

A Professional Partnership  
Noël AGNUS and  
Raynald PARKER  
Associated Bailiffs  
11 quai Anatole France  
75007 PARIS

1

[stamp: SECOND ORIGINAL]

[SD]

SERVICE OF A SUMMONS  
BEFORE THE UNITED STATES DISTRICT COURT FOR THE DISTRICT OF DELAWARE  
*International Convention of THE HAGUE*

In the year two thousand and six and [stamp: JUNE TWENTIETH]  
S.C.P. [professional partnership] Noël AGNUS and Raynald PARKER, associated Bailiffs,  
11 quai Anatole France, 75007 PARIS, by one of the undersigned,

on:

the company ALCAN RHENALU,  
whose registered office is located at 7 Place du Chancelier Adenauer 75016 PARIS,

the service having been made under the conditions specified at the end of the instrument,

At the request of:

Alcoa, Inc., a company formed in accordance with the laws of the Commonwealth of Pennsylvania,  
whose registered office is located at 390 Park Avenue, New York, NY 1022-4608, the UNITED STATES

Electing domicile at the offices of its Attorney Jeffrey L. Moyer, Esquire, Richards, Layton & Finger,  
One Rodney Square, Wilmington, DE 19899 (tel. (302) 651-7700).

I deliver to you, with a copy of this instrument, the following documents:

- document entitled "IN THE UNITED STATES DISTRICT COURT FOR THE DISTRICT OF DELAWARE," in English (55 pages), preceded by its sworn translation into French entitled "TRIBUNAL FEDERAL DE PREMIERE INSTANCE DU DISTRICT DU DELAWARE" (20 pages) accompanied by documents in English (36 pages),

These documents include a summons and complaint before the UNITED STATES DISTRICT COURT FOR THE DISTRICT OF DELAWARE

For the matter between:

ALCOA, Inc, the plaintiff,

And

ALCAN INC, a company formed under Canadian law, ALCAN CORP., a company formed in the state of Texas, ALCAN CORP., a company formed in the state of Delaware, PECHINEY S.A., a company formed under French law, ALCAN RHENALU, a company formed under French law, ALCAN PECHINEY CORP., a company incorporated in the state of Texas, PECHINEY METALS, LLC, a limited liability company incorporated in the state of Delaware, ALCAN ROLLED PRODUCTS-RAVENSWOOD, LLC, a limited liability company incorporated in the state of Delaware, defendants.

A Professional Partnership  
Noël AGNUS and  
Raynald PARKER  
Associated Bailiffs  
11 quai Anatole France  
75007 PARIS

2

I bring to your attention the time limit of **20 (twenty) consecutive days** following the day of this service, noted in this summons, during which you must serve on the plaintiff's attorney a response to the complaint that is hereby served on you.

Failing this, a default judgment shall be delivered against you according to the redress applied for in the complaint.

Any response that you may have served on the parties of this action must be filed with the clerk of the Court referred to above, within a reasonable period of time following the notification.

The undersigned Bailiff certifies that he has served this instrument, under the conditions specified herein, in accordance with French law, and that he has the authority to carry out this service.

WITHOUT PREJUDICE

[logo]

FILE No.: 000004  
6071  
MORAL 6/20/06

A Professional Partnership  
Noël AGNUS and  
Raynald PARKER  
*Associated Bailiffs*  
11 Quai Anatole France  
75007 PARIS

Tel: 01.45.56.01.02 - Fax: 01.45.56.04.73  
CCP [post office account] La Source 34-570-60 P

### RECORD OF SERVICE

Forming an integral part of the instrument indicated on the first page

INTENDED FOR: ALCAN RHENALU

FILE No.: 000004 / 6071

SERVICE OF THE INSTRUMENT:

This instrument was delivered by a Sworn Clerk according to the statements made to the latter:

To Madame Anabelle MARTIN who stated that she is a lawyer from Alcan Rhenalu, authorized to receive the envelope, and who accepted the instrument.

The letter provided for by article 658 of the New Code of Civil Procedure was sent within the time period specified by the Law, the date of the letter 6/20/06.

Certification by the Bailiff of the particulars relating to the service

The copy of this instrument (with any attached documents) includes 104 pages.

This instrument was signed by Maître Noël AGNUS

#### **COST OF THE INSTRUMENT:**

The articles refer to decree No. 96-1080 of 12/12/96

#### **INSTRUMENT SUBJECT TO A FLAT-RATE FEE**

Fixed fee (Article 6)	38.40
Calling of a case	0 00
Institution of proceedings fee (Article 13)	0.00
Travel costs (Article 18)	5.96
Sub Total	44 36
VAT 19.60%	8.69
Fixed Rate (Article 20-1)	9 15
Postage costs (Article 20-2)	0 82
Other disbursements	0.00
Total	63.02

[seal]

SCP Noël AGNUS and Raynald PARKER  
Associated Bailiffs

[logo]

11, Quai Anatole France 75007 PARIS

[signature over the seal]

Société Civile Professionnelle  
Noël AGNUS et  
Raynald PARKER  
Huissiers de Justice associés  
11 quai Anatole France  
75007 PARIS

SECOND  
ORIGINAL

SD

SIGNIFICATION D'UNE ASSIGNATION  
DEVANT LE TRIBUNAL FEDERAL DE PREMIERE INSTANCE DU DISTRICT DU DELAWARE  
*Convention Internationale de LA HAYE*

L'an deux mille six et le ~~sept~~ un

S.C.P. Noël AGNUS et Raynald PARKER, Huissiers de Justice associés,  
11 quai Anatole France, 75007 PARIS, par l'un d'eux soussigné,

à :

la société ALCAN RHENALU,  
dont le siège social est situé 7 Place du Chancelier Adenauer 75016 PARIS,

la signification étant faite dans les conditions spécifiées en fin d'acte.

A la demande de :

Alcoa, Inc, société constituée conformément aux lois du Commonwealth de Pennsylvania dont le  
siège social est situé 390 Park Avenue, New York, NY 10022-4608, ETATS UNIS

Elisant domicile chez son Avocat Jeffrey L. Moyer, Esquire Richards, Layton & Finger, One  
Rodney Square, Wilmington, DE 19899 (tel (302) 651-7700).

Je vous remets, avec la copie du présent acte, les documents suivants :

- document intitulé "IN THE UNITED STATES DISTRICT COURT FOR THE DISTRICT OF  
DELAWARE", en langue anglaise (55 pages), précédé de sa traduction jurée en langue  
française intitulée " TRIBUNAL FEDERAL DE PREMIERE INSTANCE DU DISTRICT DU  
DELAWARE " (20 pages) accompagnée des pièces en langue anglaise (36 pages),

Ces documents comportent assignation et plainte devant le TRIBUNAL FEDERAL DE  
PREMIERE INSTANCE DU DISTRICT DU DELAWARE

Pour l'affaire, entre :

ALCOA Inc, demanderesse,

Et

ALCAN INC, une société de droit canadien, ALCAN CORP. une société constituée dans l'état du  
Texas, ALCAN CORP. une société constituée dans l'état du Delaware, PECHINEY S.A, une  
société de droit français, ALCAN RHENALU, une société de droit Français, ALCAN  
PECHINEY CORP., une société constituée dans l'état du Texas, PECHINEY METALS, LLC, une  
société à responsabilité limitée incorporée dans l'état du Delaware, ALCAN ROLLED  
PRODUCTS-RAVENSWOOD, LLC, une société à responsabilité limitée incorporée dans l'état  
du Delaware, défenderesses.

Société Civile Professionnelle  
Noël AGNUS et  
Raynald PARKER  
Huissiers de Justice associés  
11 quai Anatole France  
75007 PARIS

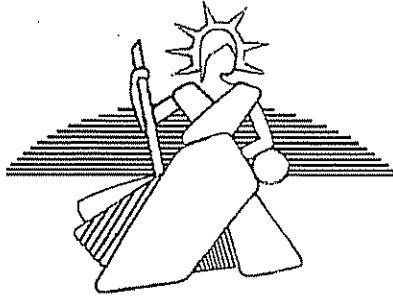
J'attire votre attention sur le délai de **20 (vingt) jours consécutifs** qui court après le jour de la présente signification, visé dans cette assignation, dans lequel vous devez signifier à l'Avocat de la demanderesse une réponse à la plainte qui vous est signifiée par la présente.

A défaut un jugement par défaut sera rendu à votre encontre selon le remède requis dans la plainte.

Toute réponse que vous aurez signifié aux parties de cette action doit être déposé auprès du greffe du Tribunal sus-visé, dans un délai raisonnable suivant la notification.

L'Huissier de Justice soussigné certifie avoir signifié le présent acte, dans les conditions qui y sont précisées, conformément à la législation française, et avoir qualité pour procéder à cette signification.

SOUS TOUTES RESERVES



N° DOSSIER : 000004  
6071  
MORAL 20/06/06

Société Civile Professionnelle  
**Noël AGNUS et  
Raynald PARKER**  
*Huissiers de Justice Associés*  
11 Quai Anatole France  
75007 PARIS

Tél : 01.45.56.01.02 - Fax : 01.45.56.04.73  
CCP La Source 34-570-60 P

## PROCES-VERBAL DE SIGNIFICATION

Faisant partie intégrante de l'acte dénommé en première page

DESTINE A : Société ALCAN RHENALU

N° DOSSIER : 000004 / 6071  
SIGNIFICATION DE L'ACTE :

Cet acte a été remis par un Clerc Assermenté suivant les déclarations faites à ce dernier :

A Madame MARTIN Anabelle qui a déclaré être Juriste d'Alcan Rhenalu, habilité à recevoir le pli, et qui a accepté l'acte

La lettre prévue par l'article 658 du Nouveau Code de Procédure Civile a été adressée dans le délai prévu par la Loi, date de la lettre 20/06/2006.

Visa par l'Huissier de Justice des mentions relatives à la signification

La copie du présent acte (avec les pièces jointes éventuelles) comporte 104 pages

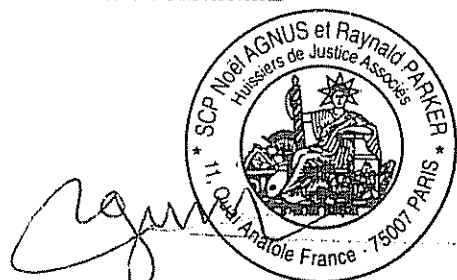
Le présent acte est signé par Maître Noël AGNUS

### COUT DE L'ACTE :

Les articles font référence au décret N°96-1080 du 12/12/96

Droit fixe (Article 6)	38,40
Appel de cause	0,00
Droit d'engagement de poursuites (Article 13)	0,00
Frais de déplacement (Article 18)	5,96
Sous Total	44,36
TVA 19,60%	8,69
Taxe Fixe (Article 20-1)	9,15
Frais d'affranchissement (Article 20-2)	0,82
Autres débours	0,00
Total	63,02

ACTE SOUMIS A LA TAXE FORFAITAIRE



IN THE UNITED STATES DISTRICT COURT  
FOR THE DISTRICT OF DELAWARE

ALCOA, INC.,

Plaintiff,

VS.

ALCAN, INC., a Canadian corporation, ALCAN  
CORP., a Texas corporation, ALCAN CORP., a  
Delaware corporation, PECHINEY, S.A., a French  
corporation, ALCAN RHENALU, a French  
corporation, ALCAN PECHINEY CORP., a Texas  
corporation, PECHINEY METALS, LLC, a Delaware  
limited liability company, ALCAN ROLLED  
PRODUCTS - RAVENSWOOD, LLC, a Delaware  
limited liability company,

Defendants.

C A. No.

06-353

TO: Alcan-Rhenalu  
c/o Secretary of State, State of Delaware  
Division of Corporations - Townsend Building  
Duke of York Street  
Dover, Delaware 19901

YOU ARE HEREBY SUMMONED and required to serve upon PLAINTIFF'S ATTORNEY  
Jeffrey L. Moyer, Esquire  
Richards, Layton & Finger  
One Rodney Square  
Wilmington, DE 19899  
(302) 651-7700

an answer to the complaint which is herewith served upon you, within twenty (20) days after service of this  
summons upon you, exclusive of the day of service. If you fail to do so, judgment by default will be taken  
against you for the relief demanded in the complaint. Any answer that you serve on the parties to this action  
must be filed with the Clerk of this Court within a reasonable period of time after service.

JUN 13 2006

CLERK PETER T. DALLEO

DATE

By [Signature]  
(By) DEPUTY CLERK

## RETURN OF SERVICE

Service of the Summons and complaint was made by me(I)	DATE 6/13/06
NAME OF SERVER (PJNT) GRANVILLE MORRIS	TITLE SPECIAL PROCESS SERVER

Check one box below to indicate appropriate method of service

☐ Served personally upon the defendant Place where served: \_\_\_\_\_

Left copies thereof at the defendant's dwelling house or usual place of abode with a person of suitable age and discretion then residing therein.

☐ Name of person with whom the summons and complaint were left: \_\_\_\_\_

☐ Returned unexecuted: \_\_\_\_\_

☒ Other (specify): SERVED: ALCAN-RHENALU C/O THE DELAWARE SECRETARY OF STATE DOVER, DE  
COPIES THEREOF WERE ACCEPTED BY NANCY POE (PROCESS AGENT)

## STATEMENT OF SERVICE FEES

TRAVEL	SERVICES	TOTAL
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## DECLARATION OF SERVER

I declare under penalty of perjury under the laws of the United States of America that the foregoing information contained in the Return of Service and Statement of Service Fees is true and correct.

Executed on 6/13/06

Date

Signature of Server

BRANDYWINE PROCESS SERVERS, LTD.

P.O. BOX 1360

WILMINGTON, DE 19899-1360

302- 475-2600



JS 44

(Rev. 12/96)

The JS-44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM)

## CIVIL COVER SHEET

382

## I.(a) PLAINTIFF

Alcoa Inc.

## DEFENDANT

See attached Exhibit 1.

(b) COUNTY OF RESIDENCE OF FIRST LISTED PLAINTIFF NEW YORK  
(EXCEPT IN U.S. PLAINTIFF CASES)

COUNTY OF RESIDENCE OF FIRST LISTED DEFENDANT \_\_\_\_\_  
(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED.

(c) ATTORNEYS (FIRM NAME, ADDRESS AND TELEPHONE NUMBER)

Jeffrey L. Moyer  
Richards, Layton & Finger  
One Rodney Square - P.O. Box 551  
Wilmington, DE 19899  
(302) 651-7700

ATTORNEYS (IF KNOWN)

## II. BASIS OF JURISDICTION (PLACE AN "X" IN ONE BOX ONLY)

- ☐ 1 U.S. Government Plaintiff ☒ 3 Federal Question (U.S. Government Not a Party)
- ☐ 2 U.S. Government Defendant ☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

## III. CITIZENSHIP OF PRINCIPAL PARTIES (PLACE AN "X" IN ONE BOX (For Diversity Cases Only) FOR PLAINTIFF AND ONE BOX FOR DEFENDANT)

	PTF	DEF		PTF	DEF
Citizen of This State	<input type="checkbox"/> 1	<input type="checkbox"/> 1	Incorporated or Principal Place of Business in This State	<input type="checkbox"/> 4	<input type="checkbox"/> 4
Citizen of Another State	<input type="checkbox"/> 2	<input type="checkbox"/> 2	Incorporated and Principal Place of Business in Another State	<input type="checkbox"/> 5	<input type="checkbox"/> 5
Citizen or Subject of a Foreign Country	<input type="checkbox"/> 3	<input type="checkbox"/> 3	Foreign Nation	<input type="checkbox"/> 6	<input type="checkbox"/> 6

## VI. ORIGIN (PLACE AN "X" IN ONE BOX ONLY)

- ☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from another district (specify) \_\_\_\_\_ ☐ 6 Multidistrict Litigation ☐ 7 Appeal to District Judge from Magistrate Judgment

## V. NATURE OF SUIT (PLACE AN "X" IN ONE BOX ONLY)

CONTRACT	TORTS	FORFEITURE/PENALTY	BANKRUPTCY	OTHER STATUTES
<input type="checkbox"/> 110 Insurance <input type="checkbox"/> 120 Marine <input type="checkbox"/> 130 Miller Act <input type="checkbox"/> 140 Negotiable Instrument <input type="checkbox"/> 150 Recovery of Overpayment & Enforcement of Judgment <input type="checkbox"/> 151 Medicare Act <input type="checkbox"/> 152 Recovery of Defaulted Student Loans (excl. Veterans) <input type="checkbox"/> 153 Recovery of Overpayment of Veteran's Benefits <input type="checkbox"/> 160 Stockholder's Suits <input type="checkbox"/> 190 Other Contract <input type="checkbox"/> 195 Contract Product Liability	<b>PERSONAL INJURY</b> <input type="checkbox"/> 310 Airplane <input type="checkbox"/> 315 Airplane Product Liability <input type="checkbox"/> 320 Assault, Libel & Slander <input type="checkbox"/> 330 Federal Employers' Liability <input type="checkbox"/> 340 Marine <input type="checkbox"/> 345 Marine Product Liability <input type="checkbox"/> 350 Motor Vehicle <input type="checkbox"/> 355 Motor Vehicle Product Liability <input type="checkbox"/> 360 Other Personal Injury  <b>CIVIL RIGHTS</b> <input type="checkbox"/> 441 Voting <input type="checkbox"/> 442 Employment <input type="checkbox"/> 443 Housing/Accommodations <input type="checkbox"/> 444 Welfare <input type="checkbox"/> 440 Other Civil Rights	<input type="checkbox"/> 362 Personal Injury - Med. Malpractice <input type="checkbox"/> 365 Personal Injury - Product Liability <input type="checkbox"/> 369 Asbestos Personal Injury Product Liability  <b>PERSONAL PROPERTY</b> <input type="checkbox"/> 370 Other Fraud <input type="checkbox"/> 371 Truth in Lending <input type="checkbox"/> 380 Other Personal Property Damage <input type="checkbox"/> 385 Property Damage Product Liability  <b>LABOR</b> <input type="checkbox"/> 710 Fair Labor Standards Act <input type="checkbox"/> 720 Labor/Mgmt. Relations <input type="checkbox"/> 730 Labor/Mgmt. Reporting & Disclosure Act <input type="checkbox"/> 740 Railway Labor Act <input type="checkbox"/> 790 Other Labor Litigation <input type="checkbox"/> 791 Empl. Ret. Inc. Security Act	<input type="checkbox"/> 422 Appeal 28 USC 158 <input type="checkbox"/> 423 Withdrawal 28 USC 157  <b>PROPERTY RIGHTS</b> <input type="checkbox"/> 820 Copyrights <input type="checkbox"/> 830 Patent <input type="checkbox"/> 840 Trademark  <b>SOCIAL SECURITY</b> <input type="checkbox"/> 861 RIA (1395b) <input type="checkbox"/> 862 Black Lung (923) <input type="checkbox"/> 863 DIWC/DIWW (405(g)) <input type="checkbox"/> 864 SSID Title XVI <input type="checkbox"/> 865 RSI (405(g))  <b>FEDERAL TAX SUITS</b> <input type="checkbox"/> 870 Taxes (U.S. Plaintiff or Defendant) <input type="checkbox"/> 871 IRS - Third Party 26 USC 7609	2006 JUN 13 AM 8:54 FILED U.S. DISTRICT COURT DISTRICT OF NEW YORK
<b>REAL PROPERTY</b> <input type="checkbox"/> 210 Land Condemnation <input type="checkbox"/> 220 Foreclosure <input type="checkbox"/> 230 Rent Lease & Eject <input type="checkbox"/> 240 Torts to Land <input type="checkbox"/> 245 Tort Product Liability <input type="checkbox"/> 290 All Other Real Property	<b>PRISONER PETITIONS</b> <input type="checkbox"/> 510 Motions to Vacate Sentence <input type="checkbox"/> Habeas Corpus: <input type="checkbox"/> 530 General <input type="checkbox"/> 535 Death Penalty <input type="checkbox"/> 540 Mandamus & Other <input type="checkbox"/> 550 Civil Rights <input type="checkbox"/> 555 Prison Condition			

VI. CAUSE OF ACTION (CITE THE U.S. CIVIL STATUTE UNDER WHICH YOU ARE FILING AND WRITE A BRIEF STATEMENT OF CAUSE. DO NOT CITE JURISDICTIONAL STATUTES UNLESS DIVERGENT FROM THE U.S.C. 9271)

VII. REQUESTED IN COMPLAINT: CHECK IF THIS IS A CLASS ACTION ☐ Under F.R.C.P. 23 DEMAND \$ \_\_\_\_\_ CHECK YES only if demanded in complaint: JURY DEMAND: YES ☒ NO ☐

VIII. RELATED CASE(S) (See instructions): IF ANY Judge Sue L. Robinson Docket Number: 99-301-SLR

DATE SIGNATURE OF ATTORNEY OF RECORD

June 13 2006

(Gregory E. Stuhlman)



FOR OFFICE USE ONLY  
RECEIPT # \_\_\_\_\_ AMOUNT \_\_\_\_\_ APPLYING IFP \_\_\_\_\_ JUDGE \_\_\_\_\_ MAG JUDGE \_\_\_\_\_

INSTRUCTIONS FOR ATTORNEYS COMPLETING CIVIL COVER SHEET FORM JS-44

## Authority For Civil Cover Sheet

The JS-44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

I. (a) **Plaintiffs - Defendants.** Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.

(b) **County of Residence.** For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the "defendant" is the location of the tract of land involved.)

(c) **Attorneys.** Enter firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section "(see attachment)".

II. **Jurisdiction.** The basis of jurisdiction is set forth under Rule 8 (a), F.R.C.P., which requires that jurisdictions be shown in pleadings. Place an "X" in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.

United States plaintiff. (1) Jurisdiction is based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States are included here.

United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an X in this box.

Federal question. (3) This refers to suits under 28 U.S.C. 1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, an act of Congress or a treaty of the United States. In cases where the U.S. is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.

Diversity of citizenship. (4) This refers to suits under 28 U.S.C. 1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked. (See Section III below; federal question actions take precedence over diversity cases.)

III. **Residence (citizenship) of Principal Parties.** This section of the JS-44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.

IV. **Cause of Action.** Report the civil statute directly related to the cause of action and give a brief description of the cause.

V. **Nature of Suit.** Place an "X" in the appropriate box. If the nature of suit cannot be determined, be sure the cause of action, in Section IV above, is sufficient to enable the deputy clerk or the statistical clerks in the Administrative Office to determine the nature of suit. If the cause fits more than one nature of suit, select the most definitive.

VI. **Origin.** Place an "X" in one of the seven boxes.

Original Proceedings. (1) Cases which originate in the United States district courts.

Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441. When the petition for removal is granted, check this box.

Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.

Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.

Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a). Do not use this for within district transfers or multidistrict litigation transfers.

Multidistrict Litigation. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407. When this box is checked, do not check (5) above.

Appeal to District Judge from Magistrate Judgment. (7) Check this box for an appeal from a magistrate's decision.

VII. **Requested in Complaint.** Class Action. Place an "X" in this box if you are filing a class action under Rule 23, F.R.C.P.

Demand. In this space enter the dollar amount (in thousands of dollars) being demanded or indicate other demand such as a preliminary injunction.

Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.

VIII. **Related Cases.** This section of the JS-44 is used to reference relating pending cases if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.  
(rev. 07/89)

## Exhibit 1

Defendants

Alcan Inc.

Alcan Corp.

Alcan Corp.

Pechiney, S.A.

Alcan-Rhenalu

Alcan Pechiney Corp.

Pechiney Metals LLC

Alcan Rolled Products - Ravenswood LLC

IN THE UNITED STATES DISTRICT COURT  
FOR THE DISTRICT OF DELAWARE

ALCOA, INC.,

Plaintiff,

vs.

ALCAN, INC., a Canadian corporation,  
ALCAN CORP., a Texas corporation, ALCAN  
CORP., a Delaware corporation, PECHINEY,  
S.A., a French corporation, ALCAN  
RHENALU, a French corporation, ALCAN  
PECHINEY CORP., a Texas corporation,  
PECHINEY METALS, LLC, a Delaware  
limited liability company, ALCAN ROLLED  
PRODUCTS - RAVENSWOOD, LLC, a  
Delaware limited liability company,

Defendants.


Case No.

FILED  
U.S. DISTRICT COURT  
DISTRICT OF DELAWARE  
2006 JUN 13 AM 8:51

RULE 7.1 CORPORATE DISCLOSURE STATEMENT

Pursuant to Rule 7.1 of the Federal Rules of Civil Procedure, this is to  
certify that Alcoa, Inc. does not have any corporate parents. No public company owns  
10% or more of the company's stock.

Dated: June 13, 2006

  
Frederick L. Cottrell, III (#2555)

cottrell@rlf.com

Jeffrey L. Moyer (#3309)

moyer@rlf.com

Gregory E. Stuhlman (#4765)

Stuhlman@rlf.com

RICHARDS, LAYTON & FINGER

One Rodney Square

P.O. Box 551

Wilmington, DE 19899

(302) 651-7700

*Attorneys for Plaintiff Alcoa, Inc.*

IN THE UNITED STATES DISTRICT COURT  
FOR THE DISTRICT OF DELAWARE

ALCOA, INC.,

Plaintiff,

vs.

ALCAN, INC., a Canadian corporation,  
ALCAN CORP., a Texas corporation, ALCAN  
CORP., a Delaware corporation, PECHINEY,  
S.A., a French corporation, ALCAN  
RHENALU, a French corporation, ALCAN  
PECHINEY CORP., a Texas corporation,  
PECHINEY METALS, LLC, a Delaware  
limited liability company, ALCAN ROLLED  
PRODUCTS - RAVENSWOOD, LLC, a  
Delaware limited liability company,

Defendants.

C. A. No.

FILED  
JUN 29 2006  
U.S. DISTRICT COURT  
DISTRICT OF DELAWARE  
153 PM 3:57

COMPLAINT

Plaintiff Alcoa, Inc. ("Alcoa"), by its undersigned attorneys, upon knowledge with respect to its own acts and on information and belief as to other matters, avers as follows:

Nature of the Claim

1. This action arises out of the continuing effort of Pechiney, S.A. and Alcan, Inc. ("Alcan"), successor-in-interest to Pechiney, S.A. and its wholly owned subsidiary, Pechiney Rhenalu (collectively, "Pechiney"), to replicate patented aluminum alloy products that have achieved widespread commercial success for Alcoa. Less than four years ago, this Court rejected Pechiney's effort to declare invalid Alcoa's United States Patent No. 5,213,639 (the "'639 patent"), and concluded that Pechiney had, in fact, infringed that patent with an aluminum

alloy developed at its research facility in Voreppe, France and manufactured at its rolling mill in Issoire, France. See Pechiney Rhenalu v. Alcoa, Inc., 224 F. Supp. 2d 773 (D. Del. 2002).

2. Alcan, which acquired Pechiney in 2004, is now marketing another, substantially equivalent alloy developed by the same engineers and technicians, working at the same Voreppe research facility, and manufactured at the same Issoire rolling mill, and has indicated its intent to offer products incorporating that infringing alloy for imminent sale in the United States, as well as to foreign manufacturers who are likely to import products containing the alloy into the United States, in violation of 35 U.S.C. §§ 271(a) and (b).

3. Alcoa therefore seeks declaratory and injunctive relief enforcing its rights under the '639 patent.

#### Parties, Jurisdiction and Venue

4. Alcoa, Inc. is a corporation organized and existing under the laws of the Commonwealth of Pennsylvania. Its principal place of business is located at 390 Park Avenue, New York, NY 10022-4608. Alcoa produces, among other things, aluminum and aluminum alloy products for aerospace applications, which it sells in the United States and throughout the world.

5. Alcan, Inc. is a Canadian corporation with its principal place of business at 1188 Sherbrooke Street West, Montreal, Quebec H3A 3G2. Alcan produces, among other things, aluminum and aluminum alloy products for aerospace applications, which it sells throughout the world.

6. Alcan derives substantial revenue from products or services consumed in the United States, including in the State of Delaware. Alcan engages in persistent corporate operations in the State of Delaware, including through numerous subsidiaries that are incorporated in the State.

7. Alcan operates in the United States and around the world through a complicated web of interlocking corporations, described below.

8. Alcan purports to do business in the United States entirely through a wholly owned subsidiary, Alcan Corp., which is incorporated in the State of Texas and has its principal place of business at 6060 Parkland Boulevard, Mayfield Heights, OH 44124

9. Among Alcan's Delaware subsidiaries is a company, also called Alcan Corp., that has its principal place of business at 8770 West Bryn Mawr, Chicago, IL 60651.

10. Alcan Corp. of Texas does business through numerous wholly owned subsidiaries, many of which, in turn, do business through other subsidiaries. Alcan Corp.'s subsidiaries include Alcan Pechiney Corp., which does business through a subsidiary, Pechiney Metals LLC, which does business through another subsidiary, Alcan Rolled Products - Ravenswood LLC.

11. Alcan Pechiney Corp., a wholly owned subsidiary of Alcan Corp., is a Texas corporation with its principal place of business at 6060 Parkland Boulevard, Mayfield Heights, OH 44124.

12. Pechiney Metals LLC, a wholly owned subsidiary of Alcan Pechiney Corp., is a Delaware limited liability company. Pechiney Metals LLC is a successor-in-interest to Pechiney Metals Corp., which was a subsidiary of Pechiney prior to Alcan's acquisition of Pechiney.

13. Alcan Rolled Products - Ravenswood, LLC ("Alcan Rolled Products"), a wholly owned subsidiary of Pechiney Metals LLC, is a Delaware limited liability company that operates the former Pechiney rolling mill in Ravenswood, West Virginia. Alcan Rolled Products is a successor-in-interest to Pechiney Rolled Products, LLC, which was a subsidiary of Pechiney



Metals Corp. prior to Alcan's acquisition of Pechiney. The Ravenswood facility, which produces aluminum and aluminum alloy products for the aerospace industry, is one of the largest aluminum rolling mills in the world. The facility is capable of manufacturing fuselage sheets and other products incorporating Alcan's latest infringing alloy for sale in the United States and around the world.

14. In December 2003, Alcan acquired a controlling stake in Pechiney, a French société anonyme that has its principal place of business at 7 place du Chancelier Adenauer, 75218 Paris Cedex 16, France. In February 2004, Pechiney, which produces aluminum and aluminum alloy products, became a wholly owned subsidiary of Alcan.

15. Alcan Rhenalu is a wholly owned subsidiary of Pechiney, S.A. that produces aluminum and aluminum alloy products for aerospace applications. Alcan Rhenalu, successor-in-interest to Pechiney Rhenalu, is a French corporation, with its principal place of business at 7 place du Chancelier Adenauer, 75218 Paris Cedex 16, France.

16. Alcan's Engineered Products division, which includes its aerospace business, is now headquartered at Pechiney's principal place of business, at 7 place du Chancelier Adenauer, 75218 Paris Cedex 16, France. The division's research facilities include the facility in Voreppe, France where Pechiney's prior infringing alloy was developed. Its production facilities include the rolling mill in Issoire, France where that infringing alloy was produced.

17. Alcan's latest infringing alloy was developed at the Voreppe facility by the same engineers and technicians who developed Pechiney's prior infringing alloy. The infringing Alcan alloy is being produced at the same rolling mill in Issoire, France, where the infringing Pechiney alloy was manufactured.

18. The Court has subject matter jurisdiction over the claims averred herein pursuant to 28 U.S.C. §§ 1331, 1333(a), 2201 and 2202. Venue in this District is proper pursuant to 28 U.S.C. §§ 1391 and 1400.

19. Pechiney previously submitted to the jurisdiction of this Court with regard to this subject matter by seeking a declaration that its substantially equivalent prior alloy did not infringe the claims of the '639 patent, and that that patent was invalid. Alcan is subject to the jurisdiction of this Court as Pechiney's successor-in-interest, as well as by virtue of the business Alcan does in the State of Delaware.

20. Each of the Alcan subsidiaries described above is complicit in the infringing conduct complained of here.

#### The '639 Patent and Pechiney's Prior Infringement

21. On May 25, 1993, the United States Patent & Trademark Office issued the '639 patent, entitled "Damage Tolerant Aluminum Alloy Products Useful for Aircraft Applications Such as Skin", which is assigned to Alcoa. A copy of the '639 patent is attached as Exhibit A.

22. The '639 patent discloses and claims certain aluminum alloy products, and methods for producing them, that are particularly useful in the construction of commercial aircraft fuselages. Relative to products made with conventional aluminum alloys that have been in use since the 1950s, the products feature improved "fracture toughness" — the ability to resist the catastrophic advance of a crack — and "fatigue crack growth resistance" — the ability to resist the slow advance of a pre-existing crack through cycles of stressing and relaxing. At the same time, the products exhibit good strength and corrosion resistance. The benefits of this invention include longer aircraft life and improved safety. In addition, by reducing or eliminating the need for so-called "crack-stoppers" — metal strips attached inside the fuselage

skin to retard the growth of cracks — the products' greater damage tolerance permits the construction of more fuel efficient aircraft.

23. In January 1996, the Aluminum Association, based in Washington, D.C., granted Alcoa's request for the International Alloy Designation "2524". This numerical designation, which indicates the allowable range of composition for the alloy under the Association's rules, is the name by which Alcoa has referred to certain products covered by the '639 patent.

24. The 2524 alloy has proved popular among aircraft manufacturers, including the two largest such manufacturers, the Boeing Co. ("Boeing") and the European Airbus consortium ("Airbus"). For example, Boeing uses 2524 for the fuselage skin of its 777-series aircraft and Airbus uses it on its A340-500 and A340-600 jets. The alloy is also used in aircraft manufactured by Canada's Bombardier, Inc. ("Bombardier") and Brazil's Embraer, S.A. ("Embraer").

25. Recognizing that its lack of a comparable alloy placed it at a serious competitive disadvantage, Pechiney sought to replicate Alcoa's invention. The initial result of that effort was an alloy developed at Pechiney's research facility in Voreppe, France and produced at Pechiney's manufacturing facility in Issoire, France that received the designation "2024A" from the Aluminum Association.

26. In 1997, Pechiney began marketing 2024A to aircraft manufacturers.

27. Aware that 2024A was, in fact, little more than a copy of 2524, Pechiney — through Pechiney Rhenalu — filed a declaratory judgment action against Alcoa in this Court in May 1999. The lawsuit sought a declaration that the '639 patent was invalid, and that 2024A did not infringe that patent.

28. Following a ten-day trial in January 2001, a jury, and then the Court (in a September 2002 opinion), rejected all of Pechiney's claims. See Pechiney Rhenalu v. Alcoa, Inc., 224 F. Supp. 2d 773 (D. Del. 2002). In a 34-page opinion, Chief Judge Robinson concluded that "Alcoa ha[d] demonstrated by a preponderance of the evidence that 2024A infringe[d] the asserted claims of the '639 patent", and that the '639 patent was both valid and enforceable. Id. at 799, 806.

29. Pechiney did not appeal that judgment, which has full collateral estoppel and res judicata effect.

#### Pechiney's Second Attempt to Replicate the 2524 Alloy

30. Although Pechiney purported to accept the district court's judgment, it was secretly pursuing an alternative means of replicating Alcoa's 2524 alloy, in willful violation of the '639 patent.

31. On or about February 18, 2003, Pechiney's second substitute alloy received the designation "2056" from the Aluminum Association. As part of its application for that designation, Pechiney represented to the Aluminum Association that it had both offered the alloy for sale and supplied it "in commercial quantities" within the preceding twelve months.

32. Pechiney's 2056 alloy is nothing more than another copy of 2524. The alloy was developed at the very same facility in Voreppe, France where Pechiney previously developed 2024A, and produced at the very same plant in Issoire, France at which Pechiney previously produced that infringing alloy. Like 2024A, 2056 contains all the essential elements of 2524. The composition of the 2056 alloy is within claims disclosed by Alcoa's '639 patent. The properties of the alloy similarly fall within claims disclosed by the '639 patent.

33. On July 7, 2003, Pechiney sought to obtain a U.S. patent for 2056 by submitting an application to the United States Patent and Trademark Office on behalf of its

employees, Timothy Warner, Ronan Dif, Bernard Bes and Hervé Ribes. Those individuals were previously involved in the design, testing and manufacture of 2024A. Each of them provided deposition testimony in Pechiney's infringement action against Alcoa, and the testimony of Messrs. Warner, Bes and Ribes was introduced at trial in that action.

34 The patent application, titled "Aircraft Structural Member Made of an Al-Cu-Mg Alloy", describes the purported invention as "an AlCuMg alloy with an improved damage tolerance, at least an equivalent mechanical strength, and improved resistance to corrosion in comparison with the prior art", to be used "as aircraft fuselage skin". The application is currently pending.

35. That same month, Alcan announced a tender offer to acquire Pechiney. Following the approval of Pechiney's board, Alcan acquired control of Pechiney in December 2003. In February, 2004, Alcan acquired the remaining shares of Pechiney that it did not own, and Pechiney became a wholly owned subsidiary of Alcan.

#### Alcan's Preparations to Offer 2056 for Imminent Sale in the United States

36. Since the acquisition, and in spite of the fact that Alcan knows that 2056 infringes Alcoa's '639 patent, Alcan has actively marketed 2056 in direct competition with Alcoa's 2524 alloy on the internet, at industry conferences and in face-to-face meetings.

37. In or about April 2004, Alcan agents met in Paris with representatives of China's First Aircraft Institute ("FAI"), which develops large commercial aircraft. The Alcan agents proposed that FAI replace 2524 with 2056 in China's Advanced Regional Jet program.

38. At or about the same time, Alcan agents met with representatives of DaimlerChrysler Aerospace Airbus GmbH, the German member of the Airbus consortium, and with representatives of Embraer, to offer 2056 for use in aircraft under development at those companies.

39. On June 8, 2004, Alcan agents Warner and Bes delivered a presentation at the AeroMat 2004 conference in Seattle titled "Development of High Strength Fuselage Sheet", in which they explicitly compared 2056 with 2524. In another presentation at the same conference titled "Advanced Metallic Solutions for Fuselage Skins", Warner, Bes and Ribes, together with Alcan agent Sjoerd van der Veen, described 2056 as an "Alcan offer" and as "[i]ndustrially ready", with a "[f]ull data package available".

40. On November 18, 2004, Alcoa's outside patent counsel wrote a letter to Alcan Corp.'s Vice President and General Counsel, William H. Jarriels, at 6060 Parkland Boulevard, Mayfield Heights, OH 44124. The caption of the letter referenced both the 2056 alloy and Alcoa's '639 patent — the very same patent over which Alcoa previously litigated against Pechiney, Alcan's predecessor-in-interest.

41. In the letter, Alcoa's counsel asked Mr. Jarriels to "[p]lease advise us of Alcan's intentions regarding the above captioned alloy".

42. On January 20, 2005, Alcoa's counsel received a written response from Eileen Burns Lerum, Vice President and Senior Litigation Counsel with Pechiney Plastic Packaging, Inc. Ms. Lerum was a member of Pechiney's legal department during the prior litigation against Alcoa concerning the '639 patent.

43. Ms. Lerum wrote on stationery bearing Alcan's name and corporate logo. Her mailing address — 8770 West Bryn Mawr Avenue, Chicago, IL 60631 — is the address of the principal place of business of Alcan Corp., of Delaware.

44. Ms. Lerum indicated that "Mr. Jarriels is no longer with the Alcan organization", but that she would be "looking into this issue" in his stead.

45. On March 17, 2005, Ms. Lerum informed Alcoa's counsel in writing that "Alcan intends to offer" 2056 products for sale.

46. Alcan has recently started to feature 2056 prominently on its corporate website as one of its "new alloys/solutions . . . for fuselage panels with high damage tolerances". A brochure available under a section of the website labeled "Global Offer" now describes 2056 as "particularly recommended for fuselage application", and indicates that the alloy can be "delivered in O or T3 temper depending on customer requirements". The brochure notes, under the heading "Availability", that "2056 clad fuselage sheets are available in the thickness range from 1,6 mm up to 8 mm". Another brochure on the Alcan website notes: "Alcan, through its Issoire plant, produces a whole range of alloys and temper qualities for specific applications. Standard alloys - meeting AMS-QQA or EN specifications - plus the newly developed sheet alloys - e.g. 2056, 6056, 6156 and 2024-HF - are available."

47. Both Airbus and Embraer have recently conducted tests on 2056 and are close to qualifying it for use as a replacement for 2524, if they have not done so already. Both companies derive substantial revenues from aircraft sales in the United States.

48. On June 12, 2006, Alcoa's attorneys wrote a letter to Alcan, Inc.'s Executive Vice President and Chief Legal Officer, David L. McAusland, advising him of Alcoa's conclusion that Alcan's activities pose an imminent threat of infringing the '639 patent, and stating Alcoa's intentions to protect its rights under the patent.

49. By virtue of the foregoing, including Pechiney's prior infringement of Alcoa's '639 patent, there is a substantial and continuing justiciable controversy between Alcoa and Alcan as to whether Alcan's imminent plans to offer 2056 for sale in the United States, or to foreign manufacturers who are likely to import products containing the alloy into the United

States, will infringe the '639 patent. Alcan's actions have created a reasonable apprehension in Alcoa of imminent harm and loss resulting from Alcan's threatened infringement of the '639 patent. Such infringement will cause Alcoa great and irreparable injury

COUNT ONE

(Infringement)

50. Alcoa repeats and reavers each of the averments of ¶¶ 1 through 49.

51. Defendants have made meaningful preparations and taken concrete steps to offer for sale within the United States aluminum alloy products, including at least Alcan's 2056 products, that infringe Alcoa's United States Patent No. 5,213,639, either literally or under the doctrine of equivalents, in violation of 35 U.S.C. § 271(a).

COUNT TWO

(Active Inducement)

52. Alcoa repeats and reavers each of the averments of ¶¶ 1 through 51.

53. Defendants have made meaningful preparations and taken concrete steps to offer for sale to foreign aircraft manufacturers aluminum alloy products, including at least Alcan's 2056 products, that infringe Alcoa's United States Patent No. 5,213,639, either literally or under the doctrine of equivalents, with knowledge that those products are likely to be used in aircraft sold in the United States, in violation of 35 U.S.C. § 271(b).



Relief Requested

WHEREFORE Alcoa demands judgment:

(a) declaring that the manufacture, use, offer for sale, or sale of the 2056 alloy within the United States, or the importation of products containing the 2056 alloy into the United States, will infringe the '639 patent;

(b) declaring that the Defendants' actions have been willful;

(c) awarding Alcoa permanent injunctive relief enjoining the Defendants and their officers, agents, servants, employees, successors and privies from marketing or offering for sale the 2056 alloy in the United States or to foreign manufacturers who are reasonably likely to offer products manufactured from the alloy for sale in the United States;

(d) awarding to Alcoa the costs of this action and reasonable attorneys fees; and

(e) awarding to Alcoa such other and further relief as the Court may deem just and proper.

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# EXHIBIT A



US005213639A

United States Patent [19]  
Colvin et al.

[11] Patent Number: 5,213,639  
[45] Date of Patent: May 25, 1993

- [54] DAMAGE TOLERANT ALUMINUM ALLOY PRODUCTS USEFUL FOR AIRCRAFT APPLICATIONS SUCH AS SKIN
- [75] Inventors: Edward L. Colvin, O'Hara Township, Allegheny County; Jocelyn L. Pettit, New Kensington, both of Pa.; Robert W. Westerlund, Bettendorf, Iowa; Paul E. Megausen, Plum Boro, Pa.
- [73] Assignee: Aluminum Company of America, Pittsburgh, Pa.
- [21] Appl. No.: 847,352
- [22] Filed: Mar. 6, 1992

## Related U.S. Application Data

- [63] Continuation-in-part of Ser. No. 572,625, Aug. 27, 1990, abandoned, Continuation-in-part of Ser. No. 572,626, Aug. 27, 1990, abandoned.
- [51] Int. Cl.<sup>5</sup> ..... C22F 1/04
- [52] U.S. Cl. .... 148/693; 148/552; 148/700; 148/417; 148/439; 428/654
- [58] Field of Search ..... 148/552, 693; 700, 417, 148/439; 428/654; 420/533

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232 Claims, 12 Drawing Sheets

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"Aluminum Alloy Development for Subsonic and Supersonic Aircraft", M. V. Hyatt, et al., *Science and Engineering of Light Metals*, published by The Japan Institute of Light Metals, Tokyo, Oct. 1991, pp. 273 to 280.

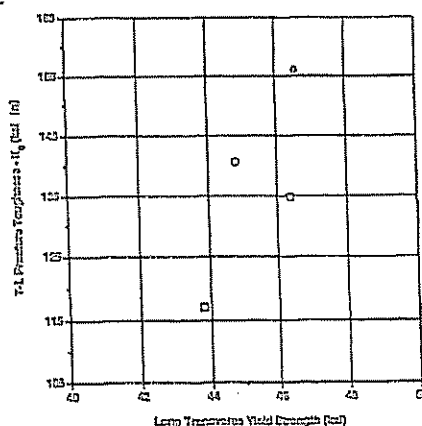
Primary Examiner—R. Dean

Assistant Examiner—Robert R. Koehler

Attorney, Agent, or Firm—Carl R. Lippert

## [57] ABSTRACT

A method of producing a sheet product and improved products having improved levels of toughness and fatigue crack growth resistance at good strength levels. The method comprises providing an aluminum base alloy containing 4 to 4.5% Cu, 1.2 to 1.5% Mg, 0.4 to 0.6% Mn, 0.12% max. Fe, 0.1% max. Si, the remainder aluminum, incidental elements and impurities and hot rolling the alloy, heating the alloy to above 910° F. and additionally hot rolling it in a range of about 600° to 900° F., solution heat treating, preferably for a time of less than about 15 minutes at a solution heat treating temperature, and rapidly cooling and naturally aging. The invention products have very good combinations of strength together with high fracture toughness or low fatigue crack growth rate, or both, making them well suited for aerospace applications such as fuselage skin. The products preferably include a corrosion protecting cladding of aluminum or aluminum alloy.



o Invention

□ Invention Comparison/Hot Roll at Low Temperature Before Hot Rolling

□ 2024-T3 Comparison/Invention Processing

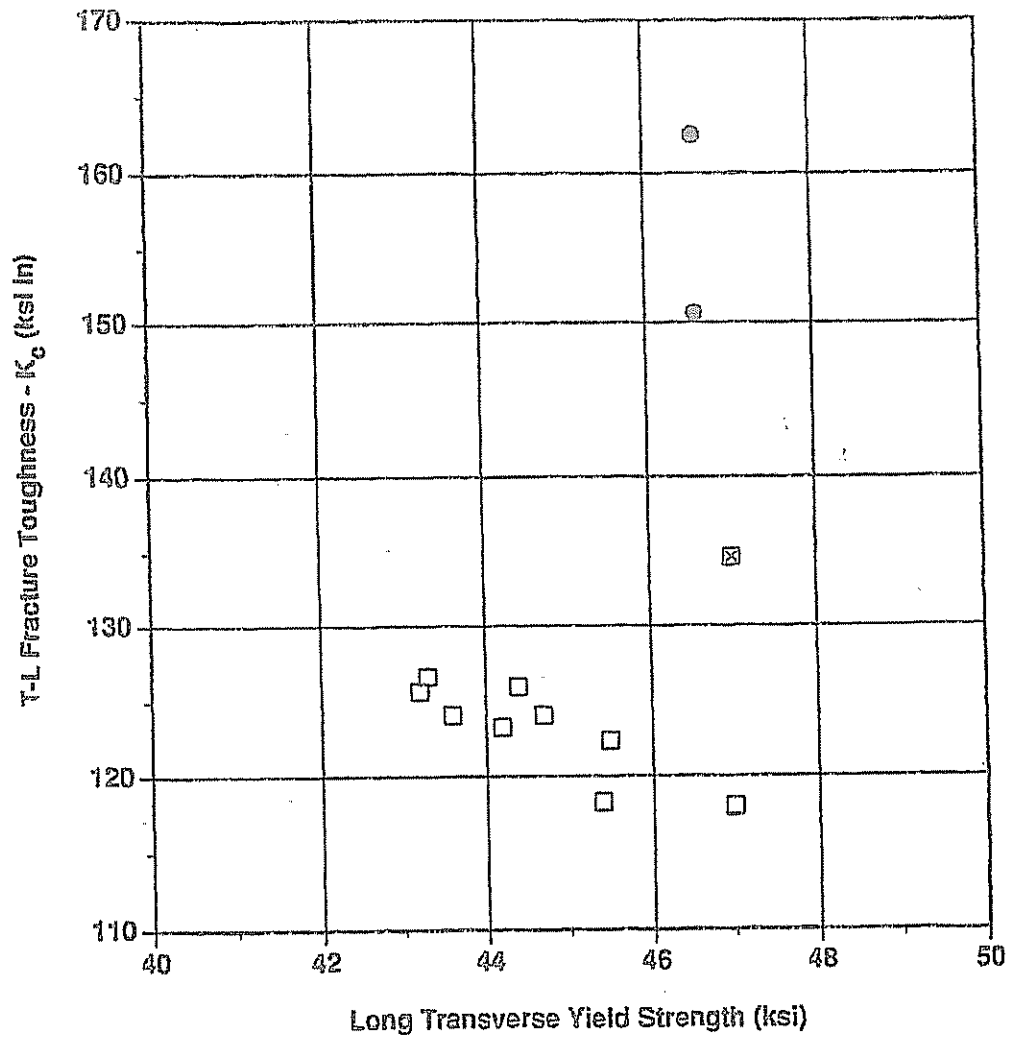
□ 2024-T3 Comparison/Conventional Processing

U.S. Patent

May 25, 1993

Sheet 1 of 12

5,213,639



- Invention
- ⊠ 2024 Composition/Invention Processing
- 2024-T3

Figure 1

U.S. Patent

May 25, 1993

Sheet 2 of 12

5,213,639

Fatigue Crack Propagation Rate vs. Crack Length  
for Invention and Special Process 2024-T3  
 $\Delta K=22 \text{ ksi}\sqrt{\text{in.}}$ ,  $R=0.33$ , T-L Orientation

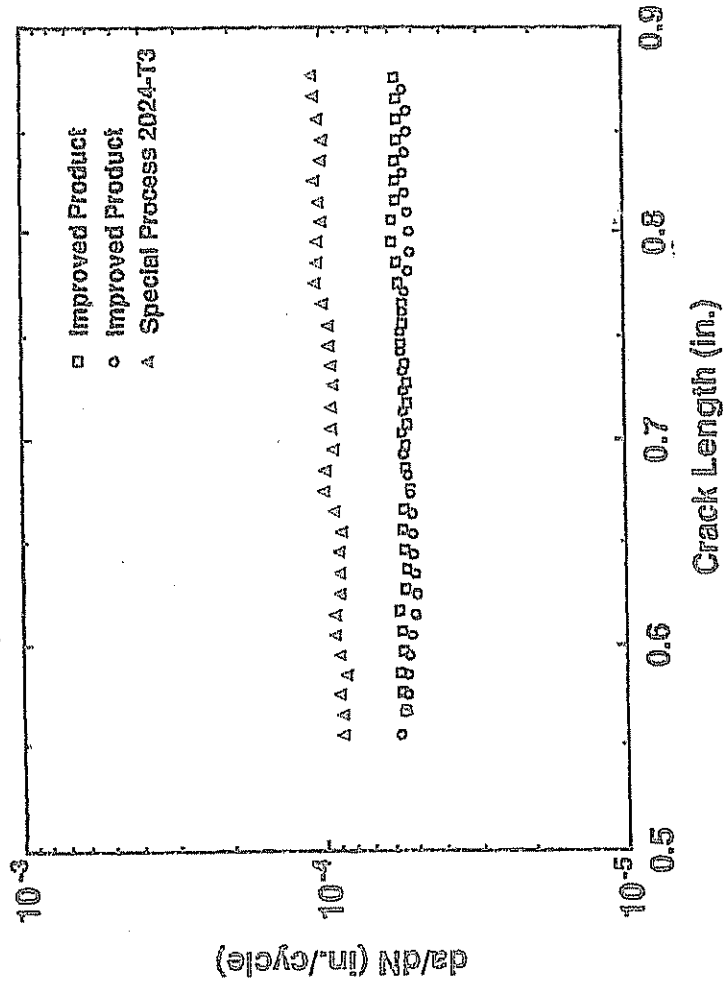


Figure 2

U.S. Patent

May 25, 1993

Sheet 3 of 12

5,213,639

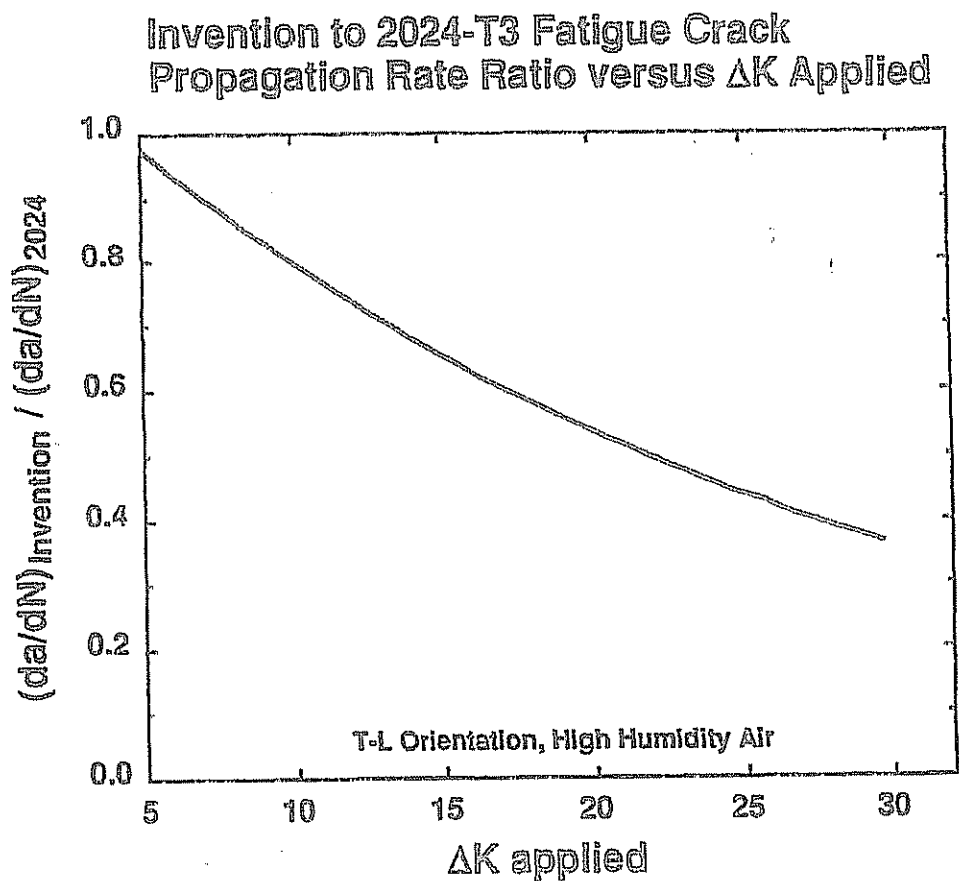


Figure 2a

U.S. Patent

May 25, 1993

Sheet 4 of 12

5,213,639

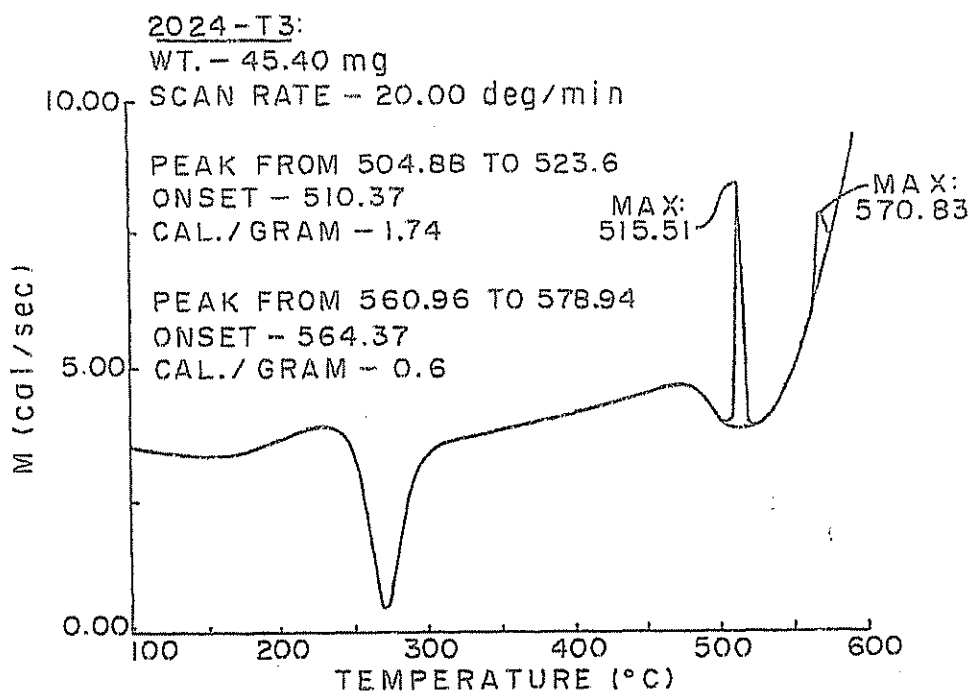


FIG. 3

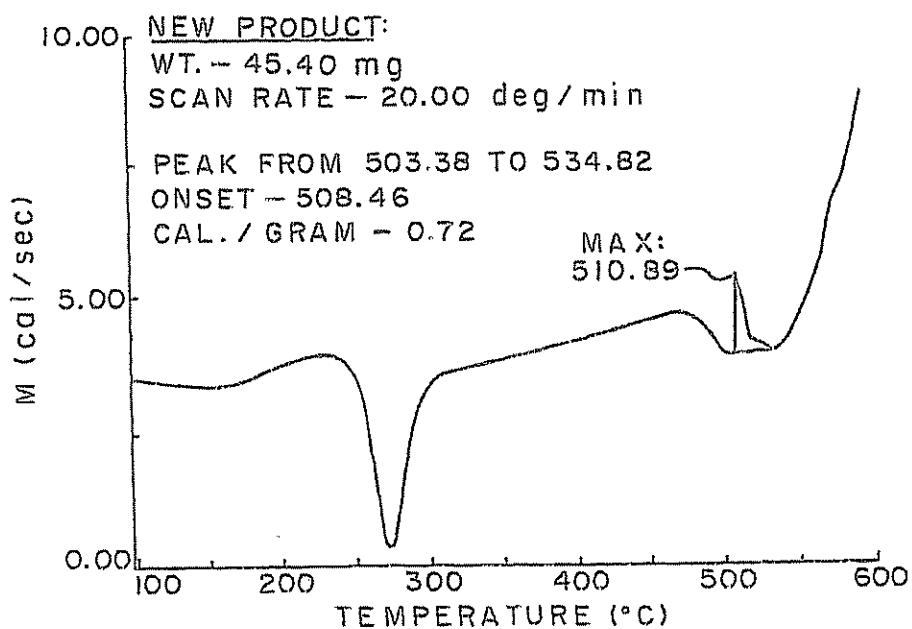


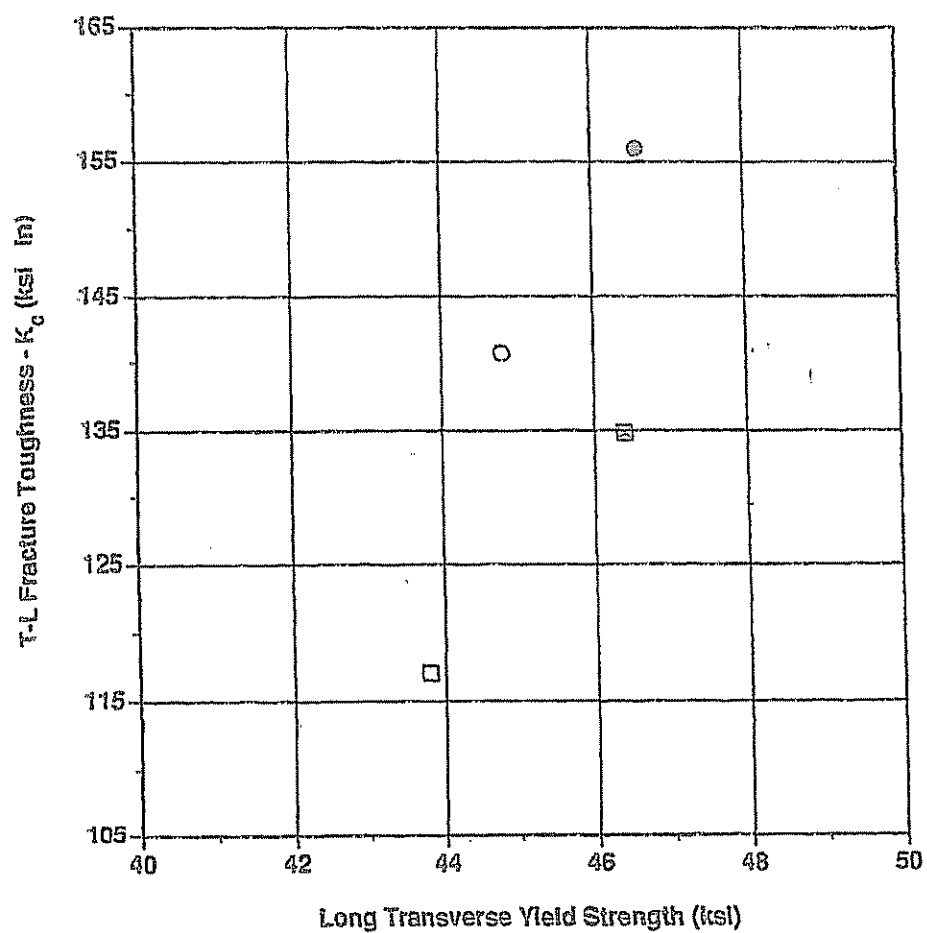
FIG. 4

U.S. Patent

May 25, 1993

Sheet 5 of 12

5,213,639



- Invention
- Invention Composition/Slab Held at Low Temperature Before Hot Rolling
- ▣ 2024-T3 Composition/Invention Processing
- 2024-T3 Composition/Conventional Processing

Figure 5



U.S. Patent

May 25, 1993

Sheet 6 of 12

5,213,639

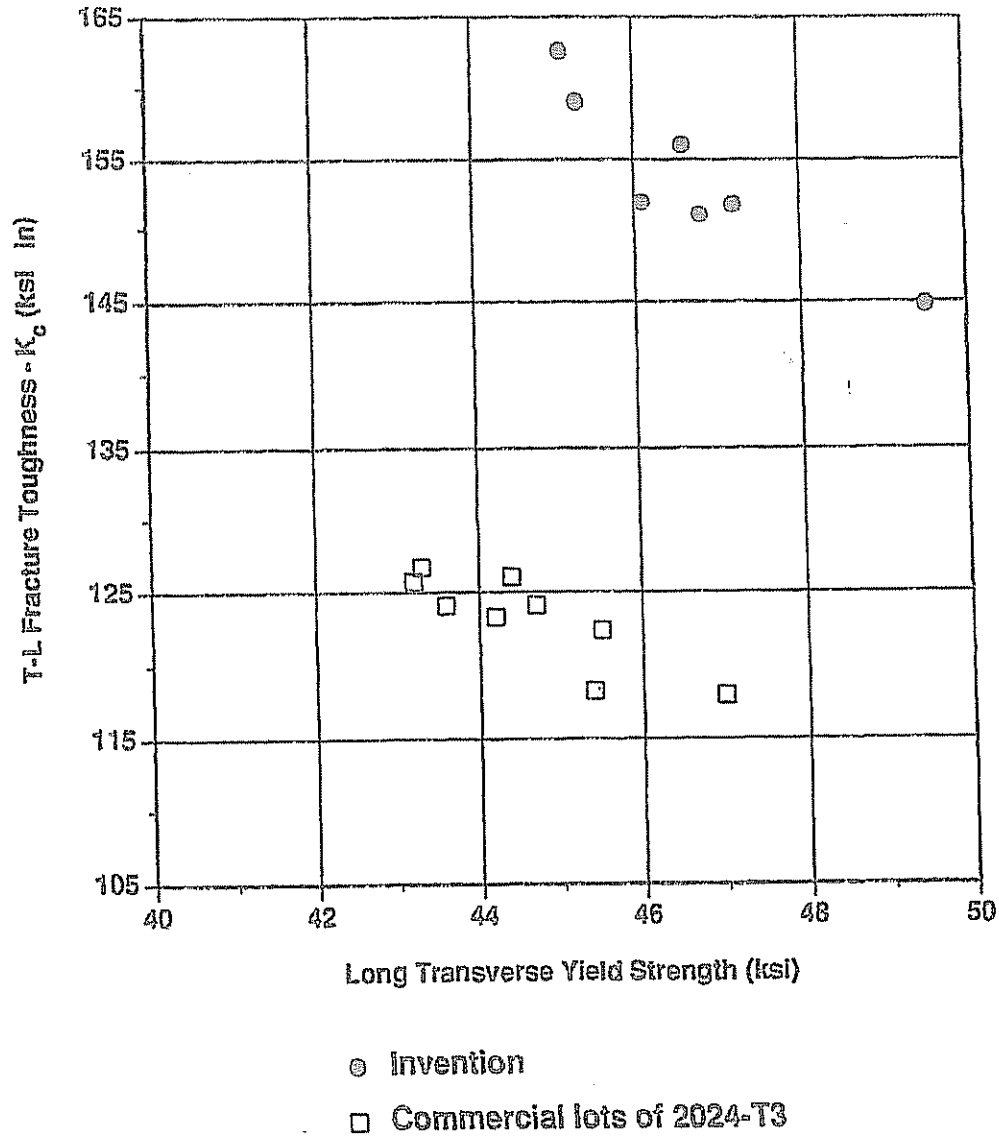


Figure 6

U.S. Patent

May 25, 1993

Sheet 7 of 12

5,213,639

Fatigue Crack Propagation Rate versus Change in  
Crack Length,  $\Delta K=30$  ksi/in.,  $R=0.1$ , High Humidity Air

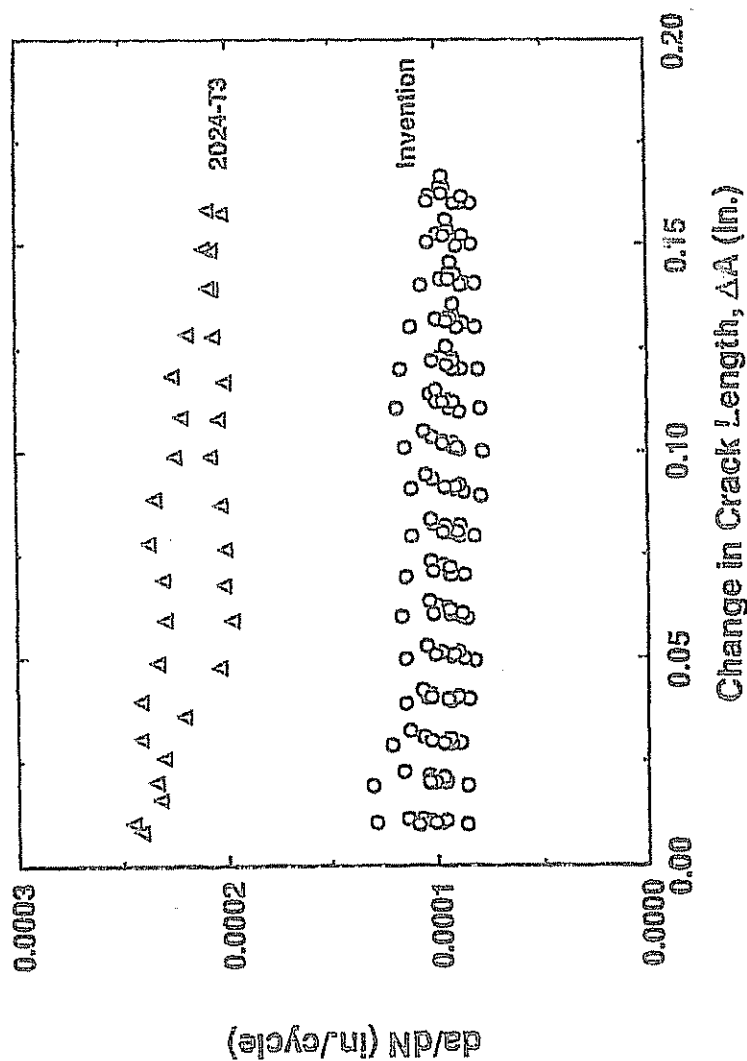


Figure 7

U.S. Patent

May 25, 1993

Sheet 8 of 12

5,213,639

Maximum Fatigue Crack Propagation Rates  
versus Applied  $\Delta K$  for Various R-Ratios

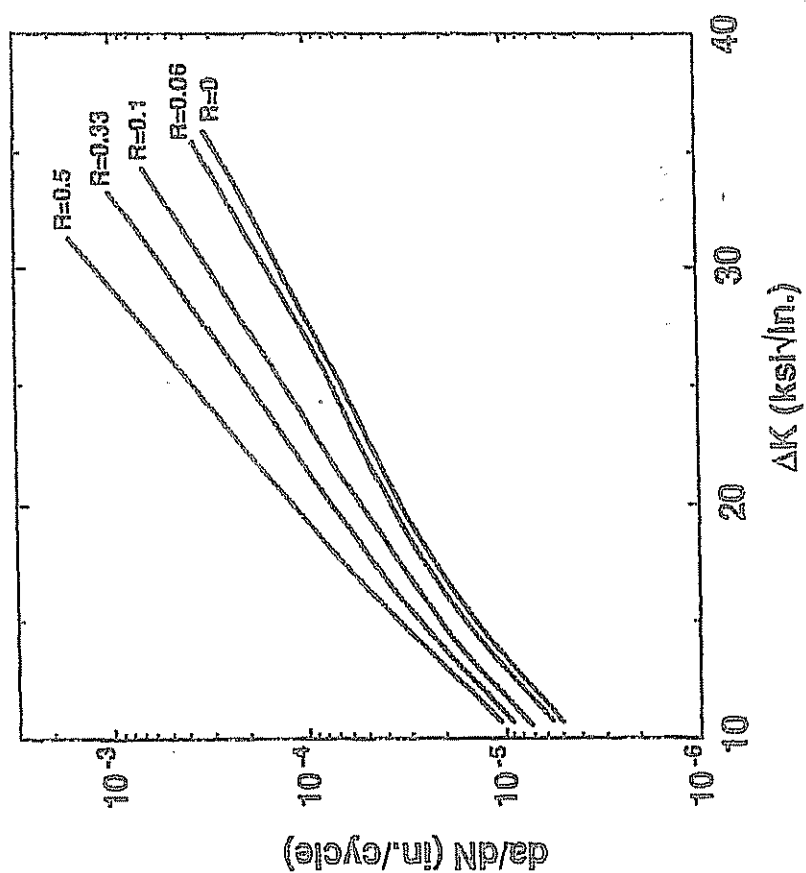


Figure 8

U.S. Patent

May 25, 1993

Sheet 9 of 12

5,213,639

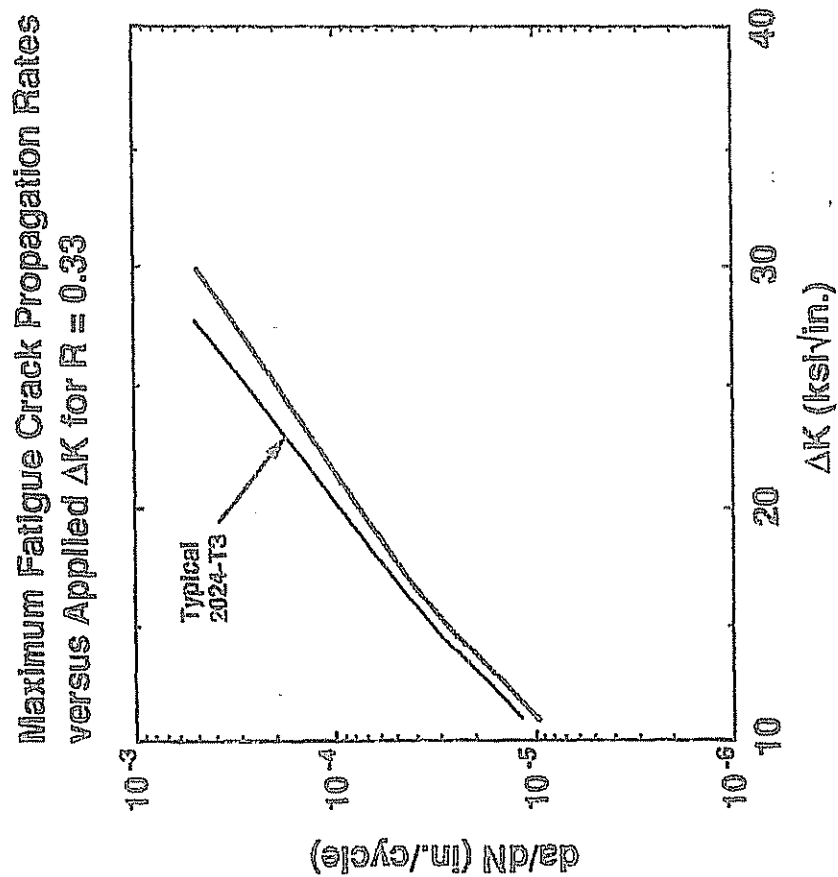


Figure 8a

U.S. Patent

May 25, 1993

Sheet 10 of 12

5,213,639

Maximum Fatigue Crack Propagation Rates  
versus Applied  $\Delta K$  for  $R = 0.1$

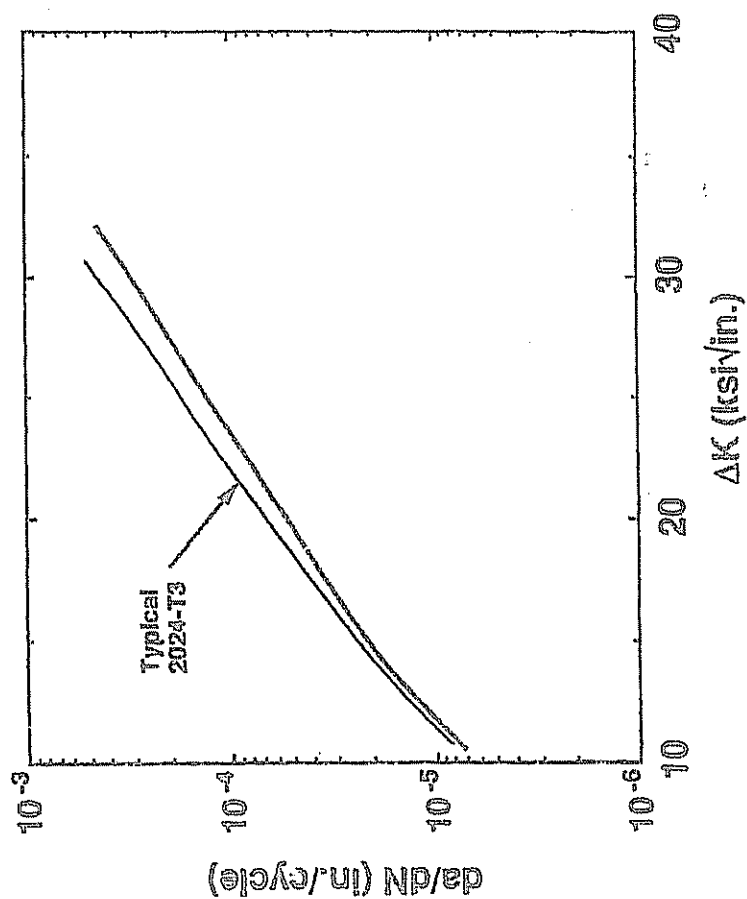


Figure 8b

U.S. Patent

May 25, 1993

Sheet 11 of 12

5,213,639

Maximum Fatigue crack Propagation Rates versus  
Applied  $\Delta K$  for Various R-Ratios, Constant  $\Delta K$  Test

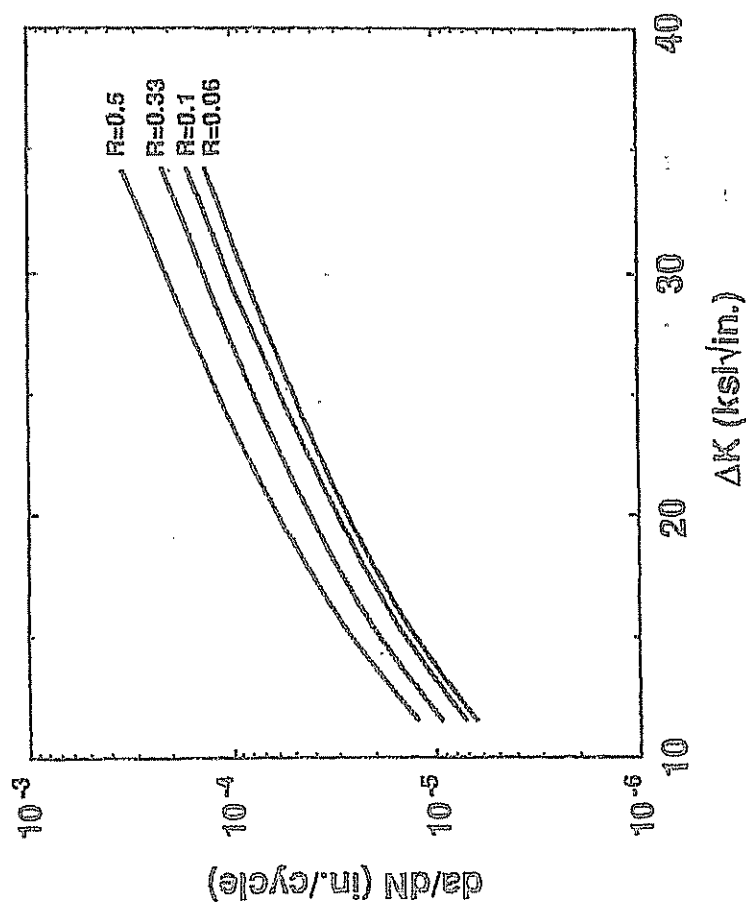


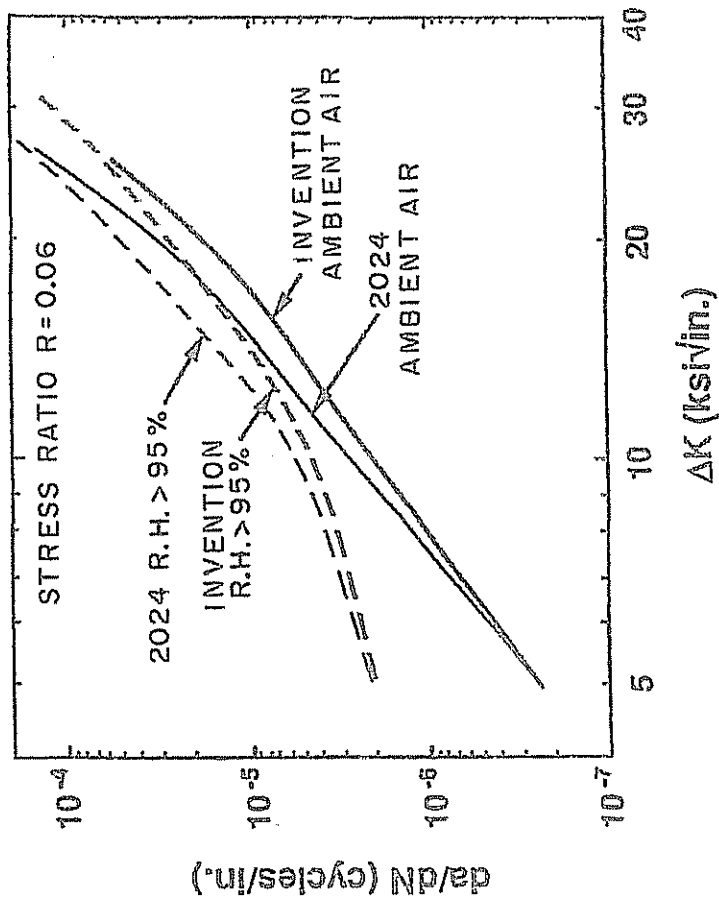
Figure 9

U.S. Patent

May 25, 1993

Sheet 12 of 12

5,213,639



Effect of Humidity on Fatigue Crack Growth Rates of Invention and 2024-T3 Sheet

Figure 10

5,213,639

1

# DAMAGE TOLERANT ALUMINUM ALLOY PRODUCTS USEFUL FOR AIRCRAFT APPLICATIONS SUCH AS SKIN

## BACKGROUND OF THE INVENTION

This application is a continuation-in-part of U.S. patent application Ser. Nos. 07/572,625 and 07/572,626, both of which were filed Aug. 27, 1990, the entire contents of which are incorporated herein by reference, and both patent applications now abandoned.

This invention relates to aluminum alloys suitable for use in aircraft applications and, more particularly, it relates to an improved aluminum alloy and processing therefor having improved resistance to fatigue crack growth and fracture toughness and suited to use as aircraft skin.

The design of commercial aircraft requires different sets of properties for different types of structures on the airplane. In many parts, resistance to crack propagation either in the form of fracture toughness or fatigue crack growth is essential. Therefore, many significant benefits can be realized by improving fracture toughness and resistance to fatigue crack propagation.

A new material with improved toughness, for example, will have a higher level of damage tolerance. On the aircraft, this translates to improved safety for passengers and crew and weight savings in the structure which allows for improved fuel economy, longer flight range, greater payload capacity or a combination of these.

Cyclic loading occurs on a commercial jet airplane with each flight as the interior of the airplane is pressurized and then depressurized. Typically, airplanes may see up to 100,000 such pressurization cycles during their normal service lifetime. Slower rates of crack growth during cyclic loading would allow for weight savings, longer service lives (more pressurizing cycles), decreased inspection frequencies and even greater passenger safety. Thus, it will be noted that great benefit is derived from improved fracture toughness and resistance to fatigue crack growth, both of which are related to cyclic loading.

U.S. Pat. No. 4,336,075 discloses the use of AA2000 type aluminum alloy for aircraft wings.

The present invention provides aluminum base alloy sheet products and a method of fabricating sheet products from a body of the alloy. Further, the invention provides aluminum alloy sheet products suitable for aircraft applications such as aircraft fuselage panels, which sheets are clad with a corrosion protecting outer layer. It can be envisioned that the invention can also have benefits in other areas of the aircraft where fracture toughness or fatigue crack growth resistance (or both) are important, such as lower wing skins, horizontal stabilizer, pressure bulkheads and fuselage reinforcements.

## SUMMARY OF THE INVENTION

A principal object of the invention is to provide an aluminum alloy and sheet product formed therefrom, the sheet product having improved fracture toughness and resistance to fatigue crack growth while maintaining high strength properties and corrosion resistance.

A further object of the present invention is to provide aluminum alloy sheet products having improved frac-

2

ture toughness and resistance to fatigue crack growth for aircraft panels.

Yet a further object of the present invention is to provide aluminum alloy sheet products and a process for producing the sheet products so as to provide improved fracture toughness and increased resistance to fatigue crack growth while still maintaining high levels of strength.

Still a further object of the invention is to provide a method for processing an aluminum alloy into clad sheet products having improved resistance to fatigue crack growth while maintaining high strength properties and corrosion resistance.

And still a further object is to provide an Al-Cu-Mg-Mn clad sheet product for use as aircraft panels such as wing or fuselage skins having improved resistance to fatigue crack growth while maintaining high strength levels and improved fracture toughness.

These and other objects will become apparent from a reading of the specification and claims and an inspection of the claims appended hereto.

In accordance with these objects, there is provided a method of producing a sheet product having improved levels of toughness and fatigue crack growth resistance while maintaining high strength, the method comprising providing a body of an aluminum base alloy preferably containing about 4.15 to 4.5% Cu, 1.2 to 1.45% Mg, 0.4 to 0.7% Mn, 0.1% max. Fe, 0.1% max. Si, the remainder substantially aluminum, incidental elements and impurities. The method further comprises heating a body of the alloy to above 900° F. to dissolve soluble constituents. Thereafter, the body is hot rolled in the range of about 600° to 900° F., and possibly cold rolled, and solution heat treated for a time of less than about 60 minutes, for example, at the solution heat treating temperature, then rapidly cooled (and, optionally, plastically deformed) and naturally aged to provide a sheet product with improved levels of fatigue crack growth resistance and fracture toughness while maintaining high strength levels.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows fracture toughness  $K_{IC}$  and yield strength data for improved material and for 2024.

FIG. 2 is a graph showing fatigue crack growth rate data versus crack length for specially processed 2024 in the solution heat treated, cold worked and naturally aged T3 temper and for the improved product in accordance with the invention.

FIG. 2a is a plot of the ratio of the fatigue crack growth rate for the improvement divided by that for 2024 versus  $\Delta K$ .

FIG. 3 is a differential scanning calorimetry curve of 2024-T3.

FIG. 4 is a differential scanning calorimetry curve of an aluminum alloy product in accordance with the invention.

FIG. 5 shows fracture toughness and yield strength data for different sheet materials from Example 2 hereof.

FIG. 6 shows fracture toughness and yield strength data for sheet products of the invention and for 2024-T3.

FIG. 7 shows fatigue crack propagation rate versus change in crack length for the invention product and for 2024-T3.

FIGS. 8, 8a and 8b are plots of maximum fatigue crack growth rate versus  $\Delta K$  for the constant load test.



5,213,639

FIG. 9 plots maximum fatigue crack growth rate versus  $\Delta K$  for the constant  $\Delta K$  test.

FIG. 10 plots fatigue crack growth rate versus  $\Delta K$  for different relative humidity levels (95% humidity and ordinary ambient).

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Typically, the alloy of the present invention preferably comprises about 3.8 or 3.9 or 4 to 4.5% Cu, 1.2 or 1.3 to 1.5 or 1.6% Mg, 0.4 to 0.8% Mn, 0.01 or 0.02 to 0.1 or 0.15% Fe, 0.01 or 0.02 to 0.1 or 0.15% Si, the balance aluminum, incidental elements and impurities. Unless indicated otherwise, all percentages for alloy elements herein are weight percent.

A preferred alloy would contain about 4.1 to 4.4% Cu, about 1.2 to 1.45% Mg, about 0.4 to 0.7% Mn, Fe not exceeding about 0.1 or 0.15%, for instance about 0.01 or 0.02 to 0.12 or 0.15% Fe, Si not exceeding about 0.1 or 0.15% maximum, for instance about 0.01, or 0.02 to 0.1 or 0.12% Si, the balance essentially aluminum, incidental elements and impurities. Impurity element Zn preferably has a maximum of 0.2 or 0.25% and Cr a maximum of 0.1 or possibly 0.2%. Zr could be added up to 0.5% Zr, with a range for Zr being 0.05 to 0.15 or 0.2 or 0.25%, such as if it is desired to make an unrecrystallized product such as a product wherein no more than 20 or 25 vol. % of the product is recrystallized. At levels of Zr above about 0.12%, coarse primary Zr-bearing particles might be formed in casting and these can be detrimental to toughness, unless care is taken to avoid such. Impurities are preferably limited to 0.05% each and the combination of impurities preferably should not exceed 0.15%. The sum total of incidental elements and impurities preferably does not exceed 0.25%, although in some cases incidental elements such as V, Hf, Cr, Ag or Sc can be included in amounts of up to about 0.5 or 1%, for instance 0.05 to 0.1 or 0.2%. A typical alloy composition would contain about 4.25% Cu, 1.35% Mg, 0.5% Mn, 0.12% max. Fe and 0.1% max. Si with Fe plus Si not totaling more than 0.20 and preferably not more than 0.15.

Mn contributes to or aids in grain size control during operations that can cause the metal to recrystallize. Very large grains are detrimental to properties such as fracture toughness, formability and corrosion resistance.

Fe and Si are normally considered impurities in aluminum and in practicing the invention their levels are preferably kept relatively low to limit formation of the constituent phases  $Al_7Cu_2Fe$  and  $Mg_2Si$  which are detrimental to fracture toughness and fatigue crack growth resistance. These phases have low solid solubility in Al-alloy and once formed cannot be eliminated by thermal treatments. Formation of  $Al_7Cu_2Fe$  and  $Mg_2Si$  phases can also lower the strength of the product because their formation reduces the amount of Cu and Mg available to form strengthening precipitates. A decrease in Fe and Si increases toughness and resistance to fatigue crack growth. Thus, in the present invention, it is preferred to control Fe to below 0.1 or 0.15% and Si to below 0.1 or 0.15%, at least where large direct chill (DC) casting is used to make the alloy ingot. Spray casting or other ingot producing techniques may make higher amounts of Fe and Si more tolerable such as 0.2% or 0.3% or 0.4% Fe or Si, or even 0.5% of each.

Preferably, Cu and Mg are carefully controlled to maintain good strength while providing the benefits in

toughness and fatigue. The Cu and Mg levels should be low enough to allow for dissolution of the slightly soluble  $Al_2CuMg$  and  $Al_2Cu$  constituent phases during high temperature processing yet high enough to increase or maximize the amount of free Cu and Mg available to adequately strengthen the alloy.

The following equations may be used to estimate the "free Cu" and "free Mg"; that is, the amount of Cu and Mg that are available to form strengthening phases.

$$Cu_{Free} = Cu_{Total} - 2.2Fe - 0.74(Mn - 0.2)$$

$$Mg_{Free} = Mg_{Total} - 1.73(Si - 0.05)$$

As well as providing the alloy product with controlled amounts of alloying elements as described herein, it is preferred that the alloy be prepared according to specific method steps in order to provide the most desirable characteristics of both strength, fracture toughness, corrosion resistance and resistance to fatigue crack growth as required, for example, for use as aircraft skins or panels. The alloy as described herein can be provided as an ingot or slab for fabrication into a suitable wrought product by casting techniques currently employed in the art for cast products with continuous casting being preferred. Slab's resulting from belt casters or roll casters also may be used. Alternately, the alloy can be spray cast into the ingot or slab wherein liquid metal drops are solidified against solidified ingot or stock.

In a broader aspect of the invention, the alloy consists essentially of about 3.8 to 4.5% Cu, 1.2 to 1.85% Mg, 0.3 to 0.78 or 0.8 or 0.9% Mn, 0.5 wt. % max. Fe, 0.5% Si, the balance aluminum, incidental elements and impurities.

The ingot or slab of the alloy of the invention may be provided with a cladding on either or both sides thereof and this composite is then processed in accordance with the invention. Such clad or composite products utilize a core of the aluminum base alloy of the invention and a cladding typically of higher purity alloy which corrosion protects the core. The cladding includes essentially unalloyed aluminum or aluminum containing not more than 0.1 or 1% of all other elements. Aluminum alloys herein designated 1XXX type refer to all Aluminum Association (AA) alloys having the number 1 as the first digit and thus include all 1000 types, 1100 types, 1200 types and 1300 types. It also is intended to encompass all other aluminum or aluminum base compositions that satisfy the AA registered composition limits for any AA alloy having 1 as the first digit in its AA designation. In general, 1XXX type aluminum or aluminum alloy can serve as the cladding. Thus, the cladding on the core may be selected from various Aluminum Association alloys such as 1060, 1045, 1100, 1200, 1230, 1135, 1235, 1435, 1145, 1345, 1250, 1350, 1170, 1175, 1180, 1185, 1285, 1188 or 1199. In addition, AA alloy 7072 containing zinc (0.8 to 1.3) can serve as the cladding and alloys such as 6003 or 6253 which contain more than 1% of alloying additions can serve as cladding. The cladding alloy is different than the core alloy and does not contain as much copper, preferably being free of substantial amounts of copper, not over 0.5 or 1%, preferably less than 0.2 or 0.3% Cu, which could interfere with corrosion protection. Other alloys could also be useful as cladding as long as they provide sufficient overall corrosion protection to the core alloy. The clad layer or layers are much thinner than the core, each constituting

5,213,639

5

1 to 15 or 20 or possibly 25% of the total composite thickness. A cladding layer more typically constitutes around 1 to 10% or so of the total composite thickness.

In addition to or in lieu of an aluminum or aluminum alloy cladding, a chemical, electrochemical or other coating or surface treatment can be used to improve corrosion resistance if desired, although cladding is presently preferred.

The alloy stock may be homogenized prior to hot working or it may be heated and directly hot rolled. If homogenization is used, it may be carried out by heating to a metal temperature in the range of 900° or 910° or 920° F. to 945° or 950° or 960° F. or, possibly as much as 1000° F., for a period of time of at least 1 hour to dissolve soluble elements and to homogenize the internal structure of the metal. It is to be understood that temperatures substantially above 945° or 950° or 960° F., for instance a temperature of 975° or 980° or 1000° F., introduce significant risk of damaging the metal and are preferably avoided. A suitable time period is about 4 hours or more in the homogenization temperature range. Normally, the soak time at the homogenizing temperature does not have to extend for more than 8 hours, however, longer times are not normally detrimental. Four to six hours at the homogenization temperature has been found to be quite suitable. A typical homogenization temperature is 920° F.

For purposes of the present invention, it can be preferred to initially hot roll a clad ingot composite without a full homogenizing. Thus, the ingot can be heated to 800° or 850° to 900° or 950° F. for a short time (or to 900° to 950° F. for a longer time in the case of homogenization) and hot worked or hot rolled to provide an intermediate gauge product, typically a slab. Hot rolling is performed wherein the starting temperature for rolling is in the range of 600° to 900° F., or even possibly higher provided melting or other ingot damage is avoided. When the use of the alloy is for fuselage skins, for example, the hot rolling is typically performed on ingot or starting stock 15 to 20 or more inches thick to provide an intermediate product or slab having a thickness of about 2 or 3 to 8 inches, the typical reductions being 40 or 50 or 60% to about 80% or more.

After hot rolling, the intermediate gauge product or slab is subjected to a reheating step. This reheating step is quite important to the present invention, particularly with respect to minimizing or avoiding soluble constituent or secondary phase particles and improving fatigue crack growth resistance and fracture toughness. Thus, in the reheating step, the intermediate gauge product or hot rolled slab is heated to a temperature of at least about 900°, or possibly a lower temperature such as 895° or maybe 890° on a somewhat less preferred basis, to a temperature of about 920° or 930° F., for example, which is near or above the solvus temperature of secondary phase particles, to dissolve or partially dissolve soluble constituents that remain from casting or may have precipitated during the preceding hot rolling. Such constituent particles include  $Al_2CuMg$ ,  $Al_2Cu$ , for example. The reheating has the effect of putting most of the Cu and Mg into solid solution. The heating can be in the range of 900° to 945° F., or possibly 950° or possibly as much as 960° F., with a preferred range being 900° or 910° to 930° F. or 940° F. It is repeated that temperatures substantially above 945° or 950° F. introduce risk of damaging the metal and decreasing the advantages achieved in practicing the invention, it being added that the reheating operation is even less tolerant of excessive

6

temperature than homogenization or heating before the first hot rolling. A reheating temperature of 975° or 980° F. could damage the metal because non-equilibrium eutectic melting would initiate or occur. Hence, such excessive temperatures are preferably avoided in practicing the invention, especially in both the reheat step and in subsequent operations such as solution heat treating where maximum temperatures are preferably limited to about 950° or 955° F., and more preferably, do not exceed 940° or 945° F., better yet not over 935° F., especially for metal which is derived from large DC cast ingots which can contain pockets having richer concentrations of alloying elements such as copper, a condition which might be relieved some by spray casting or other ingot production techniques. In the reheating operation, the intermediate gauge product can be held for about 20 minutes (or possibly 10 minutes) or one half or 1 hour to about 40 hours when the metal is in the aforesaid temperature range or near or above the solvus temperature for the soluble elements or phases. Preferably, times at said metal temperature of 900° F. or more are more than 2 hours, for instance in the range of 3 or more, preferably 4 hours or more to about 24 hours for metal derived from DC casting. It is important that the reheat is carefully controlled within the parameters set forth. If the reheating operation is substantially lower than 900° F., for example, 850° F., this can leave large volumes of coarse undissolved  $Al_2CuMg$  and  $Al_2Cu$  particles, for example, which particles can have an adverse effect on the fatigue crack growth resistance in the final product. In fact, if the reheat is below the solvus temperature, these particles can even grow in size. The presence of such particles can limit crack propagation resistance in the final sheet product.

In clad products, the temperature and duration of the reheat is very important for another reason. If the reheat temperature is excessive or if the time at reheat temperature is excessive, copper can diffuse into the higher purity aluminum cladding. This diffusion can detrimentally affect the corrosion protection afforded by the cladding. The present invention serves to both increase the dissolution of the deleterious constituent particles and yet avoid excessive high temperature thermal exposure times that can cause copper diffusion into the cladding, or at least keep diffusion within acceptable levels.

After the reheat, the intermediate product or slab is subjected to a second hot rolling operation. The second hot rolling operation is performed in the temperature range of about 500 to 900° F., preferably 600° to 850° F. In general, this is effected by moving the metal from the reheating furnace to the rolling station without the need for a separate cooling operation which could even be harmful if it involved substantial times at temperatures within 800° or 820° to 870° or 880° F. The hot rolling may be performed to a final gauge, e.g., 0.5 inch or less. Alternatively, the hot rolling step can be performed to provide a second intermediate product, typically sheet, having a thickness in the range of 0.1 to 0.25 or 0.3 inch or more. Thereafter, the second intermediate product can be cold rolled to a final gauge typically in the range of 0.01 or 0.05 to about 0.2 inch, but possibly up to about one-half inch, to produce a substantially or largely recrystallized product. An intermediate anneal may be used before cold rolling, if desired. Alternatively the product can be hot rolled to a final thickness of 0.1 or 0.2 or 0.3 inch or up to about  $\frac{1}{2}$  inch or a little more such as up to around  $\frac{3}{4}$  inch without cold rolling.

5,213,639

7

Even though hot rolling can proceed within 600° to 900° F., once the reheat step is performed effort preferably should be made to avoid prolonged exposure to temperatures substantially above 700° or 750° F. and substantially below around 900°, for instance temperatures around 850° or even 800° F. should be avoided for prolonged exposures although the relatively brief exposures encountered in hot rolling are not considered excessive. Such temperatures (for instance around 800° or 825° to 875° F. or so), if encountered for substantial time, result in lowered toughness and higher fatigue crack growth rate. Hence, the practice of the invention preferably includes measures consistent with plant practicalities and economics to avoid substantial time exposures (for example exceeding about 3 to 1 hour) at temperatures of about 780° or 800° or more to 870° or so, after the aforesaid reheating step (at 900° or 910° to about 945° or 950° F.) used in practicing the invention.

After rolling, the sheet product is subjected to a solution heat treatment preferably in the range of about 900° or 910° to 945° or 950° F., more preferably 905° to 935° or 940° F. It can be important that the solution heat treatment be carefully controlled in duration. Thus, the solution heat treatment can be accomplished in 5 minutes or even less when the metal has reached the solution temperature. The time can be extended to 15 minutes or even 60 minutes or possibly longer especially with a non-clad product. However, in clad product, care should be taken against diffusion of copper into the cladding and possible problems resulting therefrom and shorter times favor less diffusion.

Solution heat treatment in accordance with the present invention may be performed on a continuous basis. Basically, solution effects can occur fairly rapidly. In continuous treating, the sheet is passed continuously as a single web through an elongated furnace which greatly increases the heat-up rate. Long solution heat treat times may be used to dissolve the soluble constituents such as  $Al_2CuMg$  and  $Al_2Cu$ . However, long time (more than 1 hour or 2 hours) solution heat treatments should not be used on clad products because of the excessive Cu diffusion that can occur in the cladding. The continuous approach facilitates practice of the invention since a relatively rapid heat-up and short dwell time at solution temperature result in minimizing copper diffusion into the cladding. Accordingly, solution heat treating in as little as about 10 minutes, or less, for instance about 0.5 to 4 minutes, are useful in practicing the invention, especially for thin members with thin cladding. As a further aid to achieving a short heat-up time, a furnace temperature or a furnace zone temperature significantly above the desired metal temperatures provides a greater temperature head useful to speed heat-up times.

After solution heat treatment, it is important that the metal be rapidly cooled, or quenched, to prevent or minimize the uncontrolled precipitation of secondary phases, e.g.,  $Al_2CuMg$  and  $Al_2Cu$ . Thus, it is preferred in the practice of the invention that the quench rate be at least 100° F./sec from solution temperature to a temperature of 350° F. or lower. A preferred quench rate is at least 300° F./sec in the temperature range of 925° F. or more to 350° F. or less. Suitable rates can be achieved with the use of water, e.g., water immersion or water jets. Further, air or air jets may be employed.

After quenching, the sheet may be cold worked, for example, by stretching or cold rolling, or both, by up to about 10% of its original length. Typically, cold or

8

other working may be employed which produces a working effect similar to (or substantially, i.e. approximately, equivalent to) that which would be imparted by stretching at room temperature in the range of about ½% or 1% or 1½% to 2% or up to 4 or 6% or 8% of the products' original length. Stretching or other cold working such as cold rolling about 2 or 3 to 9 or 10%, preferably about 4 or 5% to about 7 or 8%, can improve strength while retaining good toughness. Yield strength can be increased around 10 ksi, for instance to levels as high as around 59 or 60 ksi or more without excessively degrading toughness, even actually increasing toughness by 5 or 6 ksi/in ( $K_{IC}$  in L-T orientation), in one test by stretching 6 or 7%. The invention in heavy sheet form, for instance, about 0.2 or 0.25 inch thick, can be stretched 6 or 7% with relative ease and gain about 10 ksi strength along with a toughness gain of about 5 or so ksi/in, or at least no degradation in toughness, or an acceptable relatively small degradation in toughness, the strength gain being significant. Cold working before aging is easier because the metal is weaker but can encounter Leuder's lines if stretching is used. Cold working after significant aging effect (for instance, a significant strength increase) requires more power because the metal is stronger but involves less likelihood of Leuder's lines or the like.

After rapidly quenching, and cold working if desired, the sheet product is aged, preferably naturally aged. By natural aging is meant to include aging at room temperature, for instance 75° F. or so, or 70° to 80° F. or so, and temperatures up to around 175° F. or 200° F. Aging at room temperature (75° F.) reaches 90% or so of its practical naturally aged strength potential within about 24 or 30 hours or so. If cold work is employed, it can precede natural aging or follow some amount thereof as stated above. Artificial aging practices which do not excessively reduce fracture toughness or fatigue crack growth resistance could also be used. For instance, aging at around 200° to 215° or 220° F. or so for 12 to 8 hours or so, or at around 280° to 300° F. or so for around an hour or so could be suitable. However, excessive combination of aging time and temperature could increase strength at an excessive penalty in toughness or fatigue resistance, or both.

If artificial aging is employed, it is believed such could be combined with a forming or shaping operation. Such age forming using a load at elevated artificial aging temperature to bend or otherwise plastically form a shaped or partially shaped product is believed to be useful in practicing the invention although excessive aging time or temperature should be avoided as stated just above. Accordingly, the invention includes combining forming and artificial aging although the toughness and fatigue crack growth rate properties could be diminished some by such. Nonetheless, it is believed that the invention products would substantially outperform age formed 2024 products with respect to the property combinations discussed herein, good combinations of strength, along with toughness or fatigue crack growth resistance, or both.

The improved product could be provided to a user in a non-solution heat treated condition, such as annealed "O" temper, and then formed and solution heat treated and aged by the user.

Conforming to these controls and using the alloy composition of the invention greatly aids the production of sheet stock having high yield strength, similar to 2024 in T3 temper, along with substantially improved



levels of fracture toughness and increased resistance to fatigue crack growth and high resistance to corrosion. The above-described controls for heating and rolling impart a substantial improvement in combination with the herein-described composition controls. That is, sheet can be produced having a minimum long transverse yield strength of about 37 or 38 ksi or 39 or 40 or 42 ksi, for instance about 43 or 44 ksi or 45 or 46 or 47 ksi, along with good minimum (guaranteeable)  $K_{Ic}$  fracture toughness or good maximum (guaranteeable) fatigue crack growth rate, or both. A long transverse yield strength over 55 ksi can be achieved if the product is cold worked, such as by stretching, after quenching. Minimum yield strength could increase to 50 ksi or more, for instance 52 or 54 ksi or more, if cold working is used after quenching.

When referring to a minimum (for instance for strength or toughness) or to a maximum (for instance for fatigue crack growth rate), such refers to a level at which specifications for materials can be written or a level at which a material can be guaranteed or a level that an airplane builder (subject to safety factor) can rely on in design. In some cases, it can have a statistical basis wherein 99% of the product conforms or is expected to conform with 95% confidence using standard statistical methods.

FIGS. 1 and 2 illustrate the extent of improvement in  $K_{Ic}$  toughness (FIG. 1) and fatigue crack growth rate (FIG. 2) of the invention over 2024 type alloy in T3 temper. Alloy 2024 is the present fuselage alloy for airliners. FIG. 1 includes a point ( $K_{Ic}$  within square) showing 2024 that had been processed according to the process of the invention. FIG. 2 shows the invention product versus 2024 that had been processed according to the invention method which enhanced its fatigue performance somewhat. The extent of the improvement for the invention is pronounced, even over 2024 that had been subjected to improved processing in accordance with the invention.

Fracture toughness is an important property to airplane designers, particularly if good toughness can be combined with good strength. By way of comparison, the tensile strength, or ability to sustain load without fracturing, of a structural component under a tensile load can be defined as the load divided by the area of the smallest section of the component perpendicular to the tensile load (net section stress). For a simple, straight-sided structure, the strength of the section is readily related to the breaking or tensile strength of a smooth tensile coupon. This is how tension testing is done. However, for a structure containing a crack or crack-like defect, the strength of a structural component depends on the length of the crack, the geometry of the structural component, and a property of the material known as the fracture toughness. Fracture toughness can be thought of as the resistance of a material to the harmful or even catastrophic propagation of a crack under a tensile load.

Fracture toughness can be measured in several ways. One way is to load in tension a test coupon containing a crack. The load required to fracture the test coupon divided by its net section area (the cross-sectional area less the area containing the crack) is known as the residual strength with units of thousands of pounds force per unit area (ksi). When the strength of the material as well as the specimen are constant, the residual strength is a measure of the fracture toughness of the material. Because it is so dependent on strength and geometry, re-

sidual strength is usually used as a measure of fracture toughness when other methods are not as useful because of some constraint like size or shape of the available material.

When the geometry of a structural component is such that it doesn't deform plastically through the thickness when a tension load is applied (plane-strain deformation), fracture toughness is often measured as plane-strain fracture toughness,  $K_{Ic}$ . This normally applies to relatively thick products or sections, for instance 0.6 or 0.75 or 1 inch or more. The ASTM has established a standard test using a fatigue pre-cracked compact tension specimen to measure  $K_{Ic}$  which has the units ksi $\sqrt{\text{in}}$ . This test is usually used to measure fracture toughness when the material is thick because it is believed to be independent of specimen geometry as long as appropriate standards for width, crack length and thickness are met. The symbol  $K$ , as used in  $K_{Ic}$ , is referred to as the stress intensity factor. A narrower test specimen width is sometimes used for thick sections and a wider test specimen width for thinner products.

Structural components which deform by plane-strain are relatively thick as indicated above. Thinner structural components (less than 0.6 to 0.75 inch thick) usually deform under plane stress or more usually under a mixed mode condition. Measuring fracture toughness under this condition can introduce variables because the number which results from the test depends to some extent on the geometry of the test coupon. One test method is to apply a continuously increasing load to a rectangular test coupon containing a crack. A plot of stress intensity versus crack extension known as an R-curve (crack resistance curve) can be obtained this way. The load at a particular amount of crack extension based on a 25% secant offset in the load vs. crack extension curve and the crack length at that load are used to calculate a measure of fracture toughness known as  $K_{R25}$ . It also has the units of ksi $\sqrt{\text{in}}$ . ASTM E561 (incorporated by reference) concerns R-curve determination.

When the geometry of the alloy product or structural component is such that it permits deformation plastically through its thickness when a tension load is applied, fracture toughness is often measured as plane-stress fracture toughness. The fracture toughness measure uses the maximum load generated on a relatively thin, wide pre-cracked specimen. When the crack length at the maximum load is used to calculate the stress-intensity factor at that load, the stress-intensity factor is referred to as plane-stress fracture toughness  $K_{Ic}$ . When the stress-intensity factor is calculated using the crack length before the load is applied, however, the result of the calculation is known as the apparent fracture toughness,  $K_{app}$ , of the material. Because the crack length in the calculation of  $K_{Ic}$  is usually longer, values for  $K_{Ic}$  are usually higher than  $K_{app}$  for a given material. Both of these measures of fracture toughness are expressed in the units ksi $\sqrt{\text{in}}$ . For tough materials, the numerical values generated by such tests generally increase as the width of the specimen increases or its thickness decreases.

Plane-stress fracture toughness can be determined from a center cracked tension test. In this test, sheet in accordance with the invention exhibits a minimum  $K_{app}$  of about 80 to 85 ksi $\sqrt{\text{in}}$ , preferably 85 to 90 or 95 or more, even 100 or more, ksi $\sqrt{\text{in}}$  (that is, 80 or more up to 100 or more ksi $\sqrt{\text{in}}$ ) when tested with an approximately 16-inch wide test specimen, and a minimum  $K_{Ic}$

5,213,639

11

within about 140 to 145, preferably within about 150 to 160 ksi√in or more, even 165 or more (that is, 140 or more up to 165 or more ksi√in). It is to be appreciated that the width of the test panel used in a toughness test can have a substantial influence on the stress intensity measured in the test. A given material may exhibit a  $K_{Ic}$  toughness of 60 ksi√in using a 6-inch wide test specimen, whereas for wider specimens the measured  $K_{Ic}$  will increase with wider and wider specimens. For instance, the same material that had a 60 ksi√in  $K_{Ic}$  toughness with a 6-inch panel could exhibit a higher  $K_{Ic}$ , for instance around 90 ksi√in, in a 16-inch panel and still higher  $K_{Ic}$ , for instance around 150 ksi√in, in a 48-inch wide panel test and a still higher  $K_{Ic}$ , for instance around 180 ksi√in, with a 60-inch wide panel test specimen. Accordingly, in referring to  $K$  values for toughness tests herein, unless indicated otherwise, such refers to testing with a 16-inch wide panel. However, those skilled in the art recognize that test results can vary depending on the test panel width and it is intended to encompass all such tests in referring to toughness. Hence, toughness substantially equivalent to or substantially corresponding to a minimum value for  $K_{Ic}$  or  $K_{Ic}$  in characterizing the invention products, while largely referring to a test with a 16-inch panel, is intended to embrace variations in  $K_{Ic}$  or  $K_{Ic}$  encountered in using different width panels as those skilled in the art will appreciate. It should be noted that toughness of prior commercially produced 2024-T3 alloy was not normally guaranteed or even routinely required to be tested; however, typical  $K_{Ic}$  values (from 16" wide specimen) for conventional 2024-T3 are generally about 125 ksi√in, but  $K_{Ic}$  values (T-L orientation) as low as 115 ksi√in and even below 110 ksi√in have been measured, all of which are well below 140 to 165 ksi or more for the minimum  $K_{Ic}$  for the invention product. Typical  $K_{Ic}$  values for 2024 using 16-inch wide test specimens are in the 70's (ksi√in) or possibly higher, but well below the levels reached with the invention. The plane-stress fracture toughness ( $K_{Ic}$ ) test applies to all thicknesses of products but may in some applications find more use in thinner products such as 1 inch or  $\frac{1}{2}$  inch or less in thickness, for example,  $\frac{1}{4}$  inch or  $\frac{1}{8}$  inch or less in thickness. The specimens for the immediately preceding tests are usually in the T-L orientation (specimen length perpendicular to rolling direction and crack parallel to the rolling direction). The testing typically is in accordance with ASTM E561 and ASTM B646 (both incorporated herein by reference).

The toughness of the improved products according to the invention is so high that it allows the aircraft designer's focus for a material's damage tolerance to switch some from toughness measurement to fatigue crack growth rate which, in its own right, is an important property. Resistance to cracking by fatigue is a very desirable property. The fatigue cracking referred to occurs as a result of repeated loading and unloading cycles, or cycling between a high and a low load such as when a wing moves up and down or a fuselage swells with pressurization and contracts with depressurization. The loads during fatigue are below the static ultimate or tensile strength of the material measured in a tensile test and they are typically below the yield strength of the material. If a crack or crack-like defect exists in a structure, repeated cyclic or fatigue loading can cause the crack to grow. This is referred to as fatigue crack propagation. Propagation of a crack by fatigue may lead to a crack large enough to propagate catastrophically

12

when the combination of crack size and loads are sufficient to exceed the material's fracture toughness. Thus, an increase in the resistance of a material to crack propagation by fatigue offers substantial benefits to aerospace structure longevity. The slower a crack propagates, the better. A rapidly propagating crack in an airplane structural member can lead to catastrophic failure without adequate time for detection, whereas a slowly propagating crack allows time for detection and corrective action or repair.

The rate at which a crack in a material propagates during cyclic loading is influenced by the length of the crack. Another important factor is the difference between the maximum and the minimum loads between which the structure is cycled. One measurement including the effects of crack length and the difference between maximum and minimum loads is called the cyclic stress intensity factor range or  $\Delta K$ , having units of ksi√in, similar to the stress intensity factor used to measure fracture toughness. The stress intensity factor range ( $\Delta K$ ) is the difference between the stress intensity factors at the maximum and minimum loads. Another measure affecting fatigue crack propagation is the ratio between the minimum and the maximum loads during cycling, and this is called the stress ratio and is denoted by  $R$ , a ratio of 0.1 meaning that the maximum load is 10 times the minimum load.

The fatigue crack propagation rate can be measured for a material using a test coupon containing a crack. One such test specimen or coupon is about 12 inches long by 4 inches wide having a notch in its center extending in a cross-wise direction (across the width; normal to the length). The notch is about 0.032 inch wide and about 0.2 inch long including a 60° bevel at each end of the slot. The test coupon is subjected to cyclic loading and the crack grows at the end(s) of the notch. After the crack reaches a predetermined length, the length of the crack is measured periodically. The crack growth rate can be calculated for a given increment of crack extension by dividing the change in crack length (called  $\Delta a$ ) by the number of loading cycles ( $\Delta N$ ) which resulted in that amount of crack growth. The

crack propagation rate is represented by  $\Delta a/\Delta N$  or 'da/dN' and has units of inches/cycle. The fatigue crack propagation rates of a material can be determined from a center cracked tension panel. The fatigue crack propagation rates for sheet in accordance with the invention are much slower than the prior 2024-T3 alloy sheet made by standard production methods when measured using a center cracked tension panel and tested at cyclic stress intensity factors of  $\Delta K$  greater than 5 ksi√in. FIG. 2a shows the fraction obtained by dividing the fatigue crack propagation rate of sheet according to the invention by the fatigue crack propagation rate of 2024-T3 alloy sheet, which fraction is plotted versus the cyclic stress intensity factor range,  $\Delta K$ . In FIG. 2a, a ratio of 1 indicates equal fatigue crack growth rate whereas a ratio of 0.5 indicates much superior performance (half the crack growth rate, or twice as good). The data show that the fatigue crack propagation rates of the invention product sheet are dramatically reduced when compared to 2024-T3 sheet especially at higher values of  $\Delta K$ . For example, at  $\Delta K=25$  ksi√in, the fatigue crack propagation rate of the sheet according to the invention is less than one half of the crack propagation rate of 2024-T3 alloy sheet. That is, a crack in 2024-T3 alloy sheet will grow more than twice as fast as a crack in the invention product sheet when subjected

5,213,639

13

to loads such that the cyclic stress intensity factor range  $\Delta K$  is 25 ksi $\sqrt{\text{in}}$ . At  $\Delta K=30$  ksi $\sqrt{\text{in}}$ , the fatigue crack growth rate for sheet according to the invention is substantially less than 40% of the crack growth rate for 2024-T3; that is, fatigue cracks in 2024 grow two-and-a-half (2½) times faster than in the invention sheet.

In a constant load amplitude test, the tensile load or pull loads for high load and low load are the same through the fatigue cycling. This causes the  $\Delta K$  level in terms of stress intensity (ksi $\sqrt{\text{in}}$ ) to increase as the crack grows during the test. This increase becomes more rapid as the test progresses, and the precision can thereby suffer in later stages as the crack grows significantly in length.

Still another technique in testing is use of a constant  $\Delta K$  gradient. In this technique, the otherwise constant amplitude load is reduced toward the latter stages of the test to slow down the rate of  $\Delta K$  increase. This adds a degree of precision by slowing down the time during which the crack grows to provide more measurement precision near the end of the test when the crack tends to grow faster. This technique allows the  $\Delta K$  to increase at a more constant rate than achieved in ordinary constant load amplitude testing.

Another way to measure fatigue crack propagation rate of sheet is by growing a crack at a constant level of the applied stress intensity factor range,  $\Delta K$ , throughout the test. The advantage of the constant  $\Delta K$  test is that it provides a repeated measure of the crack growth rate at that level of  $\Delta K$  for a relatively large distance of crack propagation. In this test, as the crack grows the tensile loads between which the panel is cycled need to be reduced as the test progresses to maintain a constant level of  $\Delta K$ . At the start of this test, an initial fatigue crack is grown from a small machined slot in the center of the panel at a low value of  $\Delta K$ , then the load is increased to give the desired level of  $\Delta K$ . When this is done, the crack propagates at an initial rate followed by a rapid decrease to a "steady state" crack propagation rate which normally is the propagation rate measured in the test. One reason for this decrease in propagation rate is believed to be the development of what is referred to as crack closure. Crack closure can occur during the unloading portion of the fatigue cycle when the crack faces come into contact with one another before the load drops to the minimum load level. Because the crack closes at a load above the minimum load, further unloading has no effect on the crack. Thus, the difference between the minimum and maximum loads which affect the crack is reduced which results in a lower effective  $\Delta K$  than the intended or nominal applied  $\Delta K$ . As a consequence, when crack closure occurs, the crack growth rate of the material is decreased. Several causes of closure are rough fracture surfaces that do not fit back together exactly during unloading, oxide buildup on the fracture surfaces that come into contact during unloading, or material at the crack tip is stretched past the yield strength (or plastically deformed) and after the crack grows through the stretched material the crack faces come into contact during unloading because the material is stretched. The latter cause is referred to as plasticity induced closure and is the cause of the initial decrease in crack growth rate observed in the constant  $\Delta K$  test. After the crack has grown for some distance at a constant  $\Delta K$  the amount of crack closure becomes constant and a steady state crack growth rate results.

When the invention product sheet is tested using a 4-inch wide panel with a center crack at a constant level

14

of the cyclic stress intensity factor range of  $\Delta K=25$  ksi $\sqrt{\text{in}}$ , a stress ratio of  $R=-0.1$ , in air with a relative humidity greater than 95%, the average steady state fatigue crack propagation rate for sheet according to the invention is  $5.54 \times 10^{-5}$ , while for commercial 2024-T3 sheet tested under the same conditions the average fatigue crack propagation rate is almost twice as fast at  $10.6 \times 10^{-5}$ . Similarly when tested at a constant cyclic stress intensity factor range of  $\Delta K=30$  ksi $\sqrt{\text{in}}$  and the same conditions as above, the average steady state fatigue crack propagation rate for the invention sheet is  $9.55 \times 10^{-5}$  and for 2024-T3 sheet the average fatigue crack propagation rate is more than twice as fast  $21.4 \times 10^{-5}$ . At  $\Delta K$  of about 22 ksi $\sqrt{\text{in}}$ , the sheet according to the invention had an average steady state fatigue crack propagation rate of  $5 \times 10^{-5}$  which was around half that for commercial 2024-T3 sheet. The specimens for the immediately preceding tests are usually in the T-L orientation. The testing is in accordance with ASTM E647-88, the entire content of which is incorporated herein by reference.

As shown in FIG. 2, the new product has very good resistance to fatigue crack propagation in tests conducted using a constant cyclic stress intensity factor range of 22 ksi $\sqrt{\text{in}}$ . This cyclic stress intensity factor range is important for the damage tolerant design of transport airplanes such as commercial airliners, but a  $\Delta K$  of 25 or 30 is also important in testing fatigue crack growth rate for aircraft application. Incidentally, in plots like FIG. 2 wherein crack length is shown on the horizontal axis and  $da/dN$  on the vertical axis, it is common for the data points on the extreme left (near the vertical axis) representing the rate at the early stage of testing to be higher than the steady state data shown in FIG. 2. The steady state data is often that of more importance.

#### Example 1

This example includes two parts. In Part 1, a 16 $\times$ 60 inch ingot containing, in accordance with the invention, 4.28% Cu, 1.38% Mg, 0.50% Mn, 0.07% Fe, 0.05% Si, balance Al was cast. The metal was clad with AA1145 then heated to approximately 875° F. and hot rolled to a slab gauge of 4.5 inches. The rolled slab was then heated to a temperature above 910° F. for 17 hours and hot rolled to a gauge of 0.176 inch. The metal was cold rolled to a final gauge of 0.100 inch before solution heat treating for 10 minutes at 925° F., quenched by cold water sprays, and stretched around 2%. The sheet was aged for 3 weeks at room temperature.

In Part 2, for comparison, an alloy with 2024 composition, 2024 being the alloy currently used for the fuselage skins of commercial jet airliners, having the approximate composition 4.6% Cu, 1.5% Mg, 0.6% Mn, 0.2% Fe, 0.1% Si, balance Al (actual composition: 4.54% Cu, 1.52% Mg, 0.64% Mn, 0.17% Fe, 0.08% Si), was processed essentially the same. It is to be noted that the 2024 comparison product does not represent typical commercial 2024 because the comparison product received processing according to the invention.

The product of the invention had a 16% higher plane stress fracture toughness ( $K_{IC}=156.5$  ksi $\sqrt{\text{in}}$  in average for 2 measurements of new product data of FIG. 1 versus 134.7 ksi $\sqrt{\text{in}}$  for the comparison special processed 2024 T-3 point of FIG. 1), and even greater improvement (around 25%) over normal 2024. Fatigue cracks for the invention product at a cyclic stress intensity range of 22 ksi $\sqrt{\text{in}}$  grew more than 44% slower



5,213,639

15

( $da/dN = 5.3 \times 10^{-5}$  in/cycle versus  $9.52 \times 10^{-5}$  in/cycle,

$$\frac{9.52 - 5.3}{9.52} = 44.33\%$$

as shown in the table below as compared to 2024 alloy even as processed according to the invention method to have better performance.

TABLE I

Fatigue Crack Propagation at Different Cyclic Stress Intensity Ranges		
Sample	$\Delta K$	$da/dN$
New Product	10	$6.70 \times 10^{-6}$
	22	$5.30 \times 10^{-5}$
	30	$1.34 \times 10^{-4}$
Specially processed 2024-T3	10	$7.91 \times 10^{-6}$
	22	$9.52 \times 10^{-5}$
	30	$3.71 \times 10^{-4}$

$\Delta K$  = Cyclic Stress Intensity Factor Range  
 $da/dN$  = Length of crack growth during one load/unload cycle. Test performed with an R-ratio (min. load/max. load) equal to 0.33

Fracture toughness was measured using a 16-inch wide, 44-inch long panel. All values given were taken in the T-L orientation which means that the applied load was parallel to the transverse direction of the sheet and the crack propagated parallel to the longitudinal direction of the sheet. Fatigue crack growth resistance was measured as the length a crack propagates during each cycle at a given stress intensity range. The measurements were made with an R-ratio of 0.33 in the T-L orientation. It is readily seen that as the stress intensity factor increases, the extent of the improvement becomes more prominent.

One possible explanation of part of the metallurgical causes of the improvement can be seen in FIGS. 3 and 4 which show differential scanning calorimetry curves. Differential scanning calorimetry offers a way to characterize the amount of coarse  $Al_2CuMg$  and  $Al_2Cu$  constituent particles. Because the eutectic is comprised of these phases with aluminum melts between 500° and 580° C., the energy associated with the melting reaction is related to the volume fraction of the particles. Prior alloy 2024 products typically exhibit a value greater than 2.2 calories/gram for the energy of fusion associated with melting three phases. Sheet material of the invention generally has a 500° to 580° C. differential scanning calorimetry peak of less than 1.0 cal/gram. FIGS. 3 and 4 show a comparison between the new product and 2024-T3 (which is the current material of choice for the fuselage skins of commercial jet aircraft) except that this particular 2024-T3 had been processed by special processing according to the invention which improved it over ordinary 2024.

Referring again to FIGS. 3 and 4 the size of the sharp peak that occurs in the temperature range of 500° to 530° C. (FIG. 3) is indicative of the amount of constituent phase or phases such as  $Al_2CuMg$  and  $Al_2Cu$  present. These phases are believed to contribute to the lowering of a material's fracture toughness and its resistance to fatigue crack growth. The new product (FIG. 4) has a much smaller peak indicating that the volume fraction of such constituent has been significantly reduced in accordance with the present invention.

Sheet material of the invention is preferably characterized by a substantial absence or sparsity of secondary phase particles, e.g.,  $Al_7Cu_2Fe$ ,  $Al_6(Fe, Mn) Al_2CuMg$  and  $Al_2Cu$  particles. That is, sheet material of the inven-

16

tion has generally not more than about 1.5 vol %, preferably not more than 1.25 vol %, of such particles larger than 0.15 square  $\mu m$  as measured by optical image analysis through a cross section of the product.

The volume fraction of total large constituent phase particles (including Fe and Si bearing particles), e.g., larger than 0.15 square  $\mu m$ , was much smaller for the new product than for the conventionally treated 2024-T3. In twelve measurements, the new product volume fraction ranged from 0.756% to 1.056%. In twelve measurements, the specially treated 2024-T3 constituent volume fraction ranged from 1.429% to 2.185%.

## EXAMPLE 2

This example includes four parts.

In Part 1 (see Example 1, Part 1, the Example 1 processing being repeated for reading convenience), a 16-inch thick by 60-inch wide ingot in accordance with the invention containing 4.28% Cu, 1.38% Mg, 0.50% Mn, 0.07% Fe, 0.05% Si, balance Al, was cast. The metal was clad with alloy 1145 then preheated to approximately 875° F. and hot rolled to a slab gauge of 4.5 inches. The slab was then reheated to a temperature above 910° F. for 17 hours and hot rolled to a gauge of 0.176 inch. The metal was cold rolled to a final gauge of 0.1 inch and solution heat treated for 10 minutes at 925° F., quenched and stretched around 2% in length. Then the sheet was naturally aged for 3-weeks at room temperature. The strength, plane stress fracture toughness and resistance to fatigue crack growth of the product of this invention are listed in the table below.

In Part 2, a 16-inch thick comparison ingot having a composition in accordance with the invention and containing 4.26% Cu, 1.37% Mg, 0.51% Mn, 0.08% Fe, 0.04% Si, balance Al, was cast. The metal was clad with alloy 1145 then it was given the same processing as described above for Part 1 except the 4.5 inch hot rolled slab was reheated to about 910° or 915° F. for about 8 hours, but then held at 850° F. for another 8 hours before the second hot rolling. In its final temper, this sheet had a lower combination of strength, toughness and resistance to fatigue crack growth than the product of this invention (see the table below). Specifically, the invention had a toughness 11.2% better than this comparison and this comparison's crack growth rate was 35% faster than that for the invention.

In Part 3 (see Example 1, Part 2, the processing being repeated for convenience in reading), a comparison ingot of 2024-T3, the alloy currently used for the fuselage skins of commercial jet airliners containing 4.54% Cu, 1.52% Mg, 0.64% Mn, 0.17% Fe, 0.08% Si, balance Al, was clad with alloy 1145 then was fabricated according to the process for the new product set forth above in Part 1 of this Example. This comparison material also had a lower combination of strength, toughness and resistance to fatigue crack growth than the product of this invention (see the table below). The invention had a 16% higher  $K_{IC}$  toughness and the comparison material's crack growth rate was over 61% faster than the invention product's at  $\Delta K = 25 \text{ ksi}\sqrt{\text{in}}$

$$\left( \frac{9.03 - 5.62}{5.62} = 61.56\% \right)$$

The table below also includes in Part 4 alloy 2024-T3 sheet clad with alloy 1145, the core 2024 containing

5,213,639

17

4.63% Cu, 1.58% Mg, 0.64% Mn, balance aluminum and impurities, using the standard 2024-T3 processing. The fatigue crack growth resistance and toughness of this sheet represent the typical behavior of the existing product that is currently used for fuselage skins of commercial aircraft.

These four sets of data (Parts 1 to 4) on commercial size product made from commercial size ingot emphasize how the damage-tolerant property improvements (fracture toughness and fatigue crack growth rate) can be achieved using the composition and process described in this invention. FIG. 5 illustrates strength versus toughness for Parts 1 to 4 of Example 2. Compared to 2024-T3, the product of this invention has over 33% higher T-L plane stress fracture  $K_{IC}$  toughness and the 2024 fatigue crack growth rate at a  $\Delta K$  of 25 was more than twice as fast as the invention product's. This shows the new product has clearly superior damage tolerant properties over the present 2024 T3 fuselage skin product. The data also show that, in order to achieve the optimum properties, it is important that both the composition and the process be in accordance with the invention.

TABLE II

EXAMPLE 2				
Example 2	Sample	Long Transverse Yield Strength	T-L Plane Stress Fracture Toughness $K_{IC}$	T-L $da/dN^a$
Part 1	Invention Product	46.6	156.5	$5.62 \times 10^{-5}$
Part 2	Invention Composition/ Low Temperature Hold Before Hot Roll	44.8	140.7	$7.6 \times 10^{-5}$
Part 3	2024 Composition/ Invention Processing	46.4	134.7	$9.08 \times 10^{-5}$
Part 4	2024-T3 Composition/ Low Temperature Reheat	43.8	117	$11.6 \times 10^{-5}$

<sup>a</sup>Test performed with an R-ratio (minimum load/maximum load) equal to 0.1 and constant  $\Delta K$  equal to 25 ksi $\sqrt{\text{in}}$ ;  $da/dN$  = Length of crack growth during one load/unload cycle. The test was a constant  $\Delta K$  test, i.e., the loads (max and min) are reduced as the crack length grows.

FIG. 6 shows typical strength versus toughness for the invention product in T3 temper and for commercial 2024-T3 for a number of commercial size lots for 0.1 inch thick sheet wherein it is clear that the invention product exhibits much better combinations of strength and T-L fracture toughness ( $K_{IC}$ ). In FIG. 6 all the 2024 exhibits  $K_{IC}$  toughness levels below 130 ksi $\sqrt{\text{in}}$  (and most below 125 ksi $\sqrt{\text{in}}$ ) whereas all the invention product exhibits  $K_{IC}$  above 130, above 135, above 140 and all equal to or exceed around 145 ksi $\sqrt{\text{in}}$ . All but one of the invention products had a  $K_{IC}$  level above 150 ksi $\sqrt{\text{in}}$  and all had yield strength equal to or above 45 ksi, whereas a substantial amount of the 2024 T3 had yield strength below 45 ksi.

FIG. 7 shows fatigue crack growth rate versus change in crack length for commercial size lots of the invention product in T3 temper versus commercial 2024-T3 for 0.1 inch thick sheet wherein it is clear that the fatigue crack growth rate for 2024 is much faster than (practically twice) the rate for the invention product.

18

The preferred maximum levels of fatigue crack growth rate for the invention product are shown in FIGS. 8 and 9 which delineate maximum crack growth rate levels for different  $\Delta K$  and R values. Each figure includes a family of curves for different R values: R=0, 0.06, 0.1, 0.33 and 0.5 being shown. For R values between two of these values the maximum  $da/dN$  fatigue crack growth rate can be interpolated by estimation along a line between the closest R curves in accordance with known practices. For instance in FIG. 8, at  $\Delta K=25$  and R=0.2, the maximum  $da/dN$  in accordance with the invention is found by interpolation between the R=0.1 and R=0.33 curves to be about  $1.5 \times 10^{-4}$ .

For FIG. 8, the tests are the constant  $\Delta K$  gradient test or the constant load test. For FIG. 9, the test is the constant  $\Delta K$  test at steady state. FIGS. 8a and 8b use curves (for R=0.1 and R=0.33) from FIG. 8 as the heavy solid lines and add light line curves representing typical 2024 data. Again, the improvement of the invention is very noticeable in that the maximum fatigue crack growth rates shown for the invention are considerably below typical rates for 2024.

FIGS. 8 and 9 are intended to broadly encompass performance for preferred products in the respective tests for FIG. 8 (constant  $\Delta K$  gradient/constant load) and FIG. 9 (constant  $\Delta K$  test). This is intended to encompass any one or more of various test conditions as to  $\Delta K$  or R (or both), for instance a constant  $\Delta K$  (FIG. 9) of 30 ksi and R=0.1. The invention product satisfies one or more of the test criteria shown in FIGS. 8 and 9, the invention encompasses products having a maximum fatigue crack growth rate as shown in FIG. 8 or 9 plus 5 or 10% or even 15%, especially at  $\Delta K$  levels of 15 or 20, or preferably above 20 ksi $\sqrt{\text{in}}$ , for instance 22 or 25 or 30 ksi $\sqrt{\text{in}}$ .  $\Delta K$ . Hence, reference to FIG. 8 or 9 in the appended claims refers to any one (or more) set of test conditions embraced in said figures to set the maximum fatigue crack growth rate for that set of conditions or specifications.

Tables III and IV are intended as a further aid in reading FIGS. 8 and 9.

TABLE III

Maximum Fatigue Crack Propagation Rates, $da/dN$ (in/cycle), of Invention Product at Selected Values of $\Delta K$ for the Constant K Gradient Test at Various R Ratios (FIG. 8)					
$\Delta K$ (ksi $\sqrt{\text{in}}$ )	$da/dN$ at R = 0	$da/dN$ at R = 0.06	$da/dN$ at R = 0.1	$da/dN$ at R = 0.33	$da/dN$ at R = 0.5
15	$1.36 \times 10^{-5}$	$1.59 \times 10^{-5}$	$2.10 \times 10^{-5}$	$2.68 \times 10^{-5}$	$3.43 \times 10^{-5}$
20	$3.38 \times 10^{-5}$	$3.79 \times 10^{-5}$	$5.26 \times 10^{-5}$	$7.44 \times 10^{-5}$	$1.18 \times 10^{-4}$
25	$6.52 \times 10^{-5}$	$7.44 \times 10^{-5}$	$1.28 \times 10^{-4}$	$1.93 \times 10^{-4}$	$3.73 \times 10^{-4}$



TABLE III-continued

Maximum Fatigue Crack Propagation Rates, $da/dN$ (in/cycle), of Invention Product at Selected Values of $\Delta K$ for the Constant $K$ Gradient Test at Various $R$ Ratios (FIG. 8)					
$\Delta K$ (ksi $\sqrt{\text{in.}}$ )	$da/dN$ at $R = 0$	$da/dN$ at $R = 0.05$	$da/dN$ at $R = 0.1$	$da/dN$ at $R = 0.33$	$da/dN$ at $R = 0.5$
30	$1.37 \times 10^{-4}$	$1.58 \times 10^{-4}$	$3.05 \times 10^{-4}$	$5.10 \times 10^{-4}$	$1.16 \times 10^{-3}$

TABLE IV

Maximum Fatigue Crack Propagation Rates, $da/dN$ (in/cycle), of Invention Product at Selected Values of $\Delta K$ for the Constant $\Delta K$ Gradient Test at Various $R$ Ratios (FIG. 9)				
$\Delta K$	$da/dN$ at $R = 0.05$	$da/dN$ at $R = 0.1$	$da/dN$ at $R = 0.33$	$da/dN$ at $R = 0.5$
15	$1.26 \times 10^{-5}$	$1.41 \times 10^{-5}$	$1.93 \times 10^{-5}$	$2.68 \times 10^{-5}$
20	$2.68 \times 10^{-5}$	$3.05 \times 10^{-5}$	$4.16 \times 10^{-5}$	$6.10 \times 10^{-5}$
25	$5.00 \times 10^{-5}$	$5.81 \times 10^{-5}$	$7.81 \times 10^{-5}$	$1.18 \times 10^{-4}$
30	$8.48 \times 10^{-5}$	$1.10 \times 10^{-4}$	$1.37 \times 10^{-4}$	$2.13 \times 10^{-4}$

One recent requirement for aircraft fuselage material is its fatigue crack growth rate ( $da/dN$ ) in a constant  $\Delta K$  test at a  $\Delta K$  of 30 ksi $\sqrt{\text{in.}}$  in a stress ratio  $R$  of 0.1 wherein the crack growth rate after crack stabilization is measured. In one series of such tests, the invention product has exhibited a maximum crack growth rate of less than about  $1.15 \times 10^{-4}$  inches per cycle at a test frequency of 2 Hz and a relative humidity exceeding 95%. In these tests, a standard center slot test specimen with a center slot 0.2 inch long is fatigue cycled at a low load to cause the crack to grow. When the crack grows to  $\frac{1}{4}$  inch long, the load is increased so that  $\Delta K = 30$  ksi $\sqrt{\text{in.}}$ . The test is continued at a constant  $\Delta K$  of 30 ksi $\sqrt{\text{in.}}$  until the crack reaches a length of one inch. The steady state fatigue crack propagation (following an initial higher rate) was measured as the crack grew from about 0.6 or 0.7 inch to about one inch long. Accordingly, it will be appreciated that the invention product can satisfy a maximum of  $1.8 \times 10^{-4}$ , or  $1.6 \times 10^{-4}$ , or preferably  $1.4 \times 10^{-4}$ , or more preferably  $1.2 \times 10^{-4}$  inches per cycle in this type test. That is, a specification maximum from about  $1.8 \times 10^{-4}$  inch per cycle down to  $1.2$  or  $1.15 \times 10^{-4}$  inch per cycle in this test is equaled or bettered by the invention product. Thus in a substantially constant  $\Delta K$  test wherein  $\Delta K$  is substantially about 30 ksi $\sqrt{\text{in.}}$  (for instance 27 or 28 to 32 ksi $\sqrt{\text{in.}}$  or 30 ksi $\sqrt{\text{in.}}$   $\pm 10$  or 15%) and  $R$  is substantially about 0.1 (for instance  $0.1 \pm 0.01$  or 0.02) the maximum fatigue crack growth rate for invention sheet product includes the levels just described for the substantially steady state part of the test.

The fatigue crack growth rate testing herein described was performed in a relative humidity (R.H.) of 95%. This high R.H. makes the test more severe and more precise over tests run in uncontrolled ambient conditions. FIG. 10 compares fatigue crack growth rate tests in 95% relative humidity versus ambient air for both the invention product and for 2024-T3 sheet. The difference attributed to ambient versus high R.H. test conditions becomes significant at  $\Delta K$ 's below about 25 ksi $\sqrt{\text{in.}}$  with the difference increasing as  $\Delta K$  decreases. For instance, at a  $\Delta K$  of 20 ksi $\sqrt{\text{in.}}$  2024-T3  $da/dN$  is a little above  $3 \times 10^{-5}$  inch/cycle for an ambient air test, whereas it increases to about  $5 \times 10^{-5}$  for a 95% R.H. test. At a  $\Delta K$  of 10 ksi $\sqrt{\text{in.}}$ , the  $da/dN$  figures for 2024-T3 are about  $3 \times 10^{-6}$  for ambient air and  $6 \times 10^{-6}$  for 95% R.H. test. At a  $\Delta K$  of 7, the difference is even greater; about  $8 \times 10^{-7}$  in air versus  $3.1 \times 10^{-6}$  in 95%

R.H. The table below further illustrates this difference

TABLE V

Alloy	Test Condition	$da/dN$		
		$\Delta K = 7$	$\Delta K = 10$	$\Delta K = 20$
2024-T3	Ambient	$8 \times 10^{-7}$	$3 \times 10^{-6}$	$3 \times 10^{-5}$
	95% R.H.	$3.1 \times 10^{-6}$	$6 \times 10^{-6}$	$5 \times 10^{-5}$
Improved Product	Ambient	$6.5 \times 10^{-7}$	$2 \times 10^{-6}$	$1.8 \times 10^{-5}$
	95% R.H.	$2.6 \times 10^{-6}$	$4.5 \times 10^{-6}$	$2.9 \times 10^{-5}$

Accordingly it can be preferable to conduct fatigue crack growth rate tests in an atmosphere having a relative humidity above 75 or 80%, preferably 85% or 90% minimum, more preferably around 95%, for instance 95%  $\pm 5\%$ .

Another factor that can influence fatigue crack growth rate test results is the frequency at which the loads are applied to the specimen in the test. This effect can be more pronounced at higher relative humidity levels in the test environment. For instance, a difference in test frequency may be minimal or virtually non-existent if the test is carried out in dry argon. However, where the test is carried out in 95% relative humidity air, a lower test frequency generally produces higher fatigue crack growth rates. Unless indicated otherwise, for the tests conducted herein, the following frequencies were employed in the fatigue crack growth rate tests, the frequency referring to the number of times per second the test specimen was cycled from low to high load level and back. For constant  $\Delta K$  tests, the frequency typically was approximately 5 Hz (5 cycles per second) for  $\Delta K$ 's other than 30 (about 2 Hz for  $\Delta K = 30$  ksi $\sqrt{\text{in.}}$ ), and for the constant  $\Delta K$  gradient tests, the frequency started at approximately 25 cycles per second, but as the crack grew to a substantial length, the number of cycles per second decreased to frequencies of as low as 5 cycles per second because of equipment limitations. As is readily apparent, it can be useful to account for differences in test conditions in comparing one test to another, and it will be appreciated that in construing the extent of the present invention and the claims appended hereto, adjustments for different test conditions may be needed to appreciate the broad scope of the invention. Accordingly, in referring to FIGS. 8 and 9 in the claims as setting maximum  $da/dN$  levels, it is intended to adjust such for differences in test conditions such as humidity, cycles per unit time, or any other influence, as well as interpreting for  $R$  values different than those shown.

The extent of the invention's improvement over conventionally produced 2024-T3 commercial products in toughness (measured as  $K_{IC}$  or as  $K_{Qpp}$ ) is at least 5 to 10%, ranging up to 20% or 30% or more. This enables guaranteeing a minimum level of toughness performance much higher than possible with conventional 2024, which normally was not specified to a minimum level of toughness, that is, toughness was not normally guaranteed for 2024.

21

5,213,639

The extent of the invention's improvement over conventionally produced 2024-T3 commercial products in reduced (lower) fatigue crack growth rate (a toughness related property) is pronounced, especially at medium to higher levels of  $\Delta K$  such as 7 ksi $\sqrt{\text{in}}$  to 15 ksi $\sqrt{\text{in}}$  or, even more importantly, at  $\Delta K$  levels above 15 ksi $\sqrt{\text{in}}$  such as  $\Delta K$  of 20 ksi $\sqrt{\text{in}}$  to 25 ksi $\sqrt{\text{in}}$  or 30 or more ksi $\sqrt{\text{in}}$   $\Delta K$  where the extent of the improvement grows with increasing  $\Delta K$ . The fatigue crack growth rate of the invention represents an improvement of at least 5 to 10 or 20% over 2024-T3 (crack grows at least 10 to 20% slower than for 2024-T3) and, especially at  $\Delta K$  levels above 20, the invention represents an improvement of at least 10% and up to 50% or even more (at 50% improvement a crack grows half as fast as for 2024-T3).

In referring to improvements over 2024 or over 2024-T3, such generally and preferably refers to similar product form, for instance plate versus plate, clad sheet versus clad sheet, or at least to 2024 product forms expected to have similar property levels to the product form being compared.

The significance of the higher toughness and better (lower) fatigue crack growth rate achieved with the invention is that the aircraft fuselage designer can save significant weight by reducing the thickness of fuselage sheet or even by redesigning the structure to eliminate or reduce straps or other auxiliary, or secondary, components which are sometimes attached to fuselage skin to reinforce against tearing. Such auxiliary components, which can be generically referred to as "crack stoppers", decrease the stress in a cracked portion of the fuselage so that the crack shouldn't propagate beyond a certain point. The product of the invention has a fracture toughness so high, and fatigue crack growth rate so low, that it can facilitate designs without such components, or at least reduced components, for example, a reduced number of, or lighter weight, "tear crack stopper" components, or both, or even elimination of such components, without having to add excessive thickness to the fuselage skin itself to compensate for the reduced reinforcement. Another advantage of the lower rate of growth of cracks by fatigue achieved by the invention is that it allows the aircraft users to increase the intervals between inspection for cracks and defects, thereby reducing the costs of the inspections and reducing costs of operation and increasing the value of the aircraft to the user. The invention product also provides for increasing the number of pressurization/depressurizing or other stressful cycles further reducing operation costs and enhancing the value of an aircraft. In addition, the toughness of the improved products is so high that the aircraft designer's focus for a material's robustness or damage tolerance can change from toughness measurements to fatigue crack growth rate.

Toughness and fatigue measuring and testing has been described in some particularity, it being understood that the aforesaid testing is intended to illustrate the good property levels of the invention but not necessarily in limitation thereof. For instance, other methods of testing may be developed over time and the good performance of the invention can be measured by those methods as well. It is to be understood that the invention product properties are generally or substantially equivalent to the described test results regardless of the particular test method used. It is to be understood that the herein described practices, especially preferred practices, impart to the invention alloy a condition

22

where it exhibits good property combinations useful in aerospace and other uses.

The invention provides products suitable for use in large airplanes, such as large commercial passenger and freight airplanes, or other aircraft or aerospace vehicles. Such products, themselves, are typically large, typically several feet in length, for instance 5 or 10 feet up to 25 or 30 feet or even 50 feet or more, and 2 to 6 or 7 feet or more wide. Yet even in these large sizes, the invention products achieve good property combinations. Hence, a particular advantage of the invention is sufficiently large size products to be suited to major structure components in aircraft, such as major aircraft fuselage components and possibly other components such as wing section, fuselage section, tail section (empennage). The invention sheet and plate product (generically referred to as rolled stock) can be shaped into a member for an airplane, such as a fuselage component or panel, or such as a wing component or panel, and the airplane can utilize the advantage of the invention as described. The shaping referred to can include bending, stretch forming, machining and other shaping operations known in the art for shaping panels or other members for aircraft, aerospace or other vehicles. Forming involving bending or other plastic deformation can be performed at room temperature or at elevated temperatures such as around 200° to 400° or so. If elevated temperatures are used in forming, such can be used in an artificial aging treatment as earlier described. The member can also include attached stiffeners or strengtheners such as structural beams attached by riveting or other means.

Unless indicated otherwise, the following definitions apply herein:

- a. The term "ksi" is equivalent to kilopounds per square inch.
- b. Percentages for a composition refer to % by weight.
- c. The term "ingot-derived" means solidified from liquid metal by a known or subsequently developed casting process rather than through powder metallurgy techniques. This term shall include, but not be limited to, direct chill casting, electromagnetic continuous casting, spray casting and any variations thereof.
- d. In stating a numerical range for an element of a composition or a temperature or other process matter or a property or an extent of improvement or any other matter herein, and apart from and in addition to the customary rules for rounding off numbers, such is intended to specifically designate and disclose each number, including each fraction and/or decimal, between the stated minimum and maximum for said range. (For example, a range of 1 to 10 discloses 1.1, 1.2 ... 1.9, 2, 2.1, 2.2 ... and so on, up to 10. Similarly, a range of 500 to 1000 discloses 501, 502 ... and so on, up to 1000, including every number and fraction or decimal therewithin.) "Up to x" means "x" and every number less than "x", for instance up to 5 discloses 0.01 ... 0.1 ... 1 and so on up to 5.

While the invention is described in terms of certain specifics and embodiments, the claims herein are intended to encompass all equivalents and everything encompassed within the spirit of the invention.

Having thus described the invention, what is claimed is:

1. A method of producing an aluminum product comprising:

23

5,213,639

(a) providing stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;

(b) hot working said stock;

(c) heating said stock above about 895° F. to less than 975° F.;

(d) hot rolling said stock;

(e) solution heat treating;

(f) cooling.

2. The method according to claim 1 wherein said alloy contains one or more elements from the group consisting of 0.02 to 0.4 % Zr, 0.01 to 0.5% V, 0.01 to 0.4% Hf, 0.01 to 0.2% Cr, 0.01 to 1% Ag and 0.01 to 0.5% Sc, percentages being by weight.

3. The method according to claim 1 wherein said alloy contains less than 0.25% Fe and less than 0.25% Si, percentages being by weight.

4. The method according to claim 1 wherein said alloy contains not more than about 0.15% Fe and not more than about 0.15% Si, percentages being by weight.

5. The method according to claim 1 wherein said heating in recitation (c) is within about 900° to less than 975° F.

6. The method according to claim 1 wherein said heating in recitation (c) is within about 900° to 960° F.

7. The method according to claim 1 wherein said heating in recitation (c) is within about 905° to 950° F.

8. The method according to claim 1 wherein said heating in recitation (c) is within about 910° to 945° F.

9. The method according to claim 1 wherein said heating and solution heat treating are within about 910° to 935° F.

10. The method according to claim 1 wherein said heating above about 895° F. is longer than 2 hours.

11. The method according to claim 1 wherein said heating above about 895° F. is 3 or more hours.

12. The method according to claim 7 wherein said heating within about 910° to 945° F. is 4 to 24 hours.

13. The method according to claim 1 wherein, after said cooling, a working effect is imparted substantially equivalent to stretching at least 1% at room temperature.

14. The method according to claim 1 wherein, after said cooling, a working effect is imparted substantially equivalent to stretching at least 3% at room temperature.

15. The method according to claim 1 wherein, after said cooling, a working effect is imparted substantially equivalent to stretching at least 4% at room temperature.

16. The method according to claim 1 wherein, after said cooling and at least some significant aging effect, a working effect is imparted substantially equivalent to stretching at least 1% at room temperature.

17. The method according to claim 13 wherein said working effect includes stretching.

18. The method according to claim 13 wherein said working effect includes cold rolling.

19. The method according to claim 1 wherein said method includes, after said cooling, artificially aging above room temperature.

20. The method according to claim 1 wherein said method includes, after said cooling, artificially aging above room temperature, and during said artificial aging, forming or deforming the metal.

24

21. The method according to claim 1 wherein, subsequent to said cooling, a forming or shaping operation is performed above room temperature.

22. A method of producing an aluminum sheet or plate product comprising:

(a) providing stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to less than 0.2% iron, about 0.01 to less than 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;

(b) hot rolling said stock;

(c) heating the hot rolled stock within about 900° to 965° F.;

(d) further hot rolling said stock;

(e) cold rolling said stock;

(f) solution heat treating.

23. The method according to claim 22 wherein said heating in recitation (c) and said solution heat treating are within about 905° to 950° F.

24. The method according to claim 22 wherein said alloy contains not more than about 0.15% Fe and not more than about 0.15% Si, percentages being by weight.

25. The method according to claim 22 wherein said alloy contains, by weight, not more than about 0.15% Fe and not more than about 0.15% Si and said heating in recitation (c) and said solution heat treating are within about 905° to 945° F and said sheet or plate is naturally aged.

26. The method according to claim 22 wherein said heating in recitation (c) is for at least 3 hours.

27. The method according to claim 22 wherein said heating in recitation (c) is for at least 4 hours.

28. A method of producing an aluminum sheet or plate product comprising:

(a) providing stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to less than 0.2% iron, about 0.01 to less than 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;

(b) hot rolling said stock;

(c) heating said hot rolled stock within about 900° to 965° F.;

(d) further hot rolling said stock;

(e) solution heat treating.

29. The method according to claim 28 wherein said heating and solution heat treating are within about 905° to 950° F.

30. The method according to claim 28 wherein said alloy contains, by weight, not more than about 0.15% Fe and not more than about 0.15% Si.

31. The method according to claim 28 wherein said alloy contains, by weight, not more than about 0.15% Fe and not more than about 0.15% Si and said heating and solution heat treating are within about 905° to 950° F. and said sheet or plate is naturally aged.

32. The method according to claim 28 wherein said heating is for at least 3 hours.

33. The method according to claim 28 wherein said heating is for more than 2 hours.

34. A method of producing a clad aluminum product comprising:

(a) providing stock comprising:



5,213,639

25

- (i) an aluminum alloy consisting essentially of, by weight, about 3.3 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;
- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot working said stock;
- (c) heating said stock within about 900° to less than 975° F;
- (d) further hot rolling said stock;
- (e) solution heat treating.
- 35. The method according to claim 34 wherein said alloy contains, by weight, not more than about 0.15% for Fe and not more than about 0.15% for Si.
- 36. The method according to claim 34 wherein said heating is within about 900° to 950° F.
- 37. The method according to claim 34 wherein both said heating and said solution heat treating are within about 905° to 950° F.
- 38. A method of producing a clad aluminum sheet or plate product comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing less than about 0.2% iron and less than about 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock;
  - (c) heating said stock within about 900° to 960° F;
  - (d) hot rolling said stock;
  - (e) cold rolling said stock;
  - (f) solution heat treating within about 900° to 950° F.
- 39. The method according to claim 38 wherein said hot rolling in recitation (b) reduces the thickness of the stock by at least 40%.
- 40. The method according to claim 38 wherein said alloy contains, by weight, 0.15% max. Fe and 0.15% max. Si.
- 41. The method according to claim 38 wherein said alloy contains, by weight, 0.15% max. Fe and 0.15% max. Si and said heating and solution heat treating are within about 905° to 950° F.
- 42. The method according to claim 38 wherein said heating is for at least 3 hours.
- 43. The method according to claim 38 wherein said heating is for at least 4 hours.
- 44. A method of producing a clad aluminum sheet or plate product comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock to a reduction in thickness of at least 40%;
  - (c) heating said stock within about 900° to 965° F;
  - (d) hot rolling said stock;
  - (e) solution heat treating at at least 900° F.

26

- 45. The method according to claim 44 wherein said heating and solution heat treating are within 905° to 950° F.
- 46. The method according to claim 44 wherein said alloy contains, by weight, 1.2 to 1.6% Mg.
- 47. The method according to claim 44 wherein said alloy contains, by weight, 1.2 to 1.6% Mg and 4 to 4.5% Cu.
- 48. The method according to claim 44 wherein said heating is for at least 3 hours.
- 49. The method according to claim 44 wherein said heating is for at least 4 hours.
- 50. A method of producing a clad aluminum product having good strength along with good fracture toughness or good resistance to fatigue crack growth, or both, said method comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.8% manganese, and containing about 0.01 to less than 0.2% iron, about 0.01 to less than 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock;
  - (c) heating said stock to at least 900° F. but not so high a temperature as to prevent achieving the aforesaid properties;
  - (d) further hot rolling said stock;
  - (e) solution heat treating;
  - (f) cooling.
- 51. A method of producing a clad aluminum sheet or plate product comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% max. iron and not more than about 0.15% max. silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock;
  - (c) heating the hot rolled stock within about 900° to 960° F;
  - (d) further hot rolling said stock;
  - (e) cold rolling said stock;
  - (f) solution heat treating;
  - (g) cooling;
  - (h) natural aging.
- 52. The method according to claim 51 wherein said alloy contains, by weight, not more than about 0.12% Fe and not more than about 0.1% Si.
- 53. The method according to claim 51 wherein said heating is for more than 2 hours.
- 54. The method according to claim 51 wherein said heating and said solution heat treating is within about 905° to 950° F.
- 55. The method according to claim 51 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.
- 56. A method of producing an aluminum sheet or plate product comprising:
  - (a) providing stock comprising

5,213,639

27

- an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.78% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
- (b) hot rolling said stock;
  - (c) heating said hot rolled stock within about 900° to less than 975° F.;
  - (d) further hot rolling said stock;
  - (e) solution heat treating;
  - (f) stretching;
  - (g) natural aging.
57. The method according to claim 56 wherein said alloy contains, by weight, not more than about 0.12% Fe and not more than about 0.1% Si.
58. The method according to claim 56 wherein said heating is for more than 2 hours.
59. The method according to claim 56 wherein said heating and said solution heat treating are within about 905° to 950° F.
60. The method according to claim 56 wherein said hot rolling in recitation (b) reduces the thickness by at least 40%.
61. A method of producing a clad aluminum product comprising:
- (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock, comprising rolling within 600° to 900° F., to a reduction in thickness of at least 40%;
  - (c) heating said stock within about 905° to 950° F. for about 3 to 24 hours;
  - (d) further hot rolling said stock comprising rolling within 550° to 900° F.;
  - (e) solution heat treating at at least 900° F.
62. A method of producing a clad aluminum sheet product comprising:
- (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock, comprising rolling within 600° to 900° F., to a reduction in thickness of at least 40%;
  - (c) heating said stock within about 905° to 950° F. for more than 2 hours;
  - (d) further hot rolling said stock comprising rolling within 550° to 900° F.;
  - (e) cold rolling said stock to a thickness within 0.03 to about 0.3 inch sheet;
  - (f) solution heat treating at a temperature of at least 900° F.
  - (g) stretching;
  - (h) natural aging.

28

63. A method of producing a clad aluminum product having good strength along with good fracture toughness or good resistance to fatigue crack growth, or both, said method comprising:

- (a) providing aluminous stock comprising:
  - (i) an aluminum alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
  - (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock;
- (c) heating said hot rolled stock within about 900° to 960° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating temperature at at least 900° F.;
- (f) cooling;
- (g) imparting a cold work effect;
- (h) natural aging.

64. A method of producing a clad aluminum product having good strength along with good fracture toughness or good resistance to fatigue crack growth, or both, said method comprising:

- (a) providing aluminous stock comprising:
  - (i) an aluminum alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
  - (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock;
- (c) heating said hot rolled stock within about 900° to 960° F. for more than 2 hours;
- (d) further hot rolling said stock;
- (e) solution heat treating at at least 900° F.;
- (f) cooling;
- (g) natural aging;
- (h) imparting a cold work effect.

65. In a method wherein an aluminum alloy stock is shaped into an airplane member, the improvement wherein said stock is provided by a method comprising:

- (a) providing aluminous stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;
- (b) hot rolling said stock;
- (c) heating said stock within about 900° to less than 975° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating.

66. In a method wherein an aluminum alloy stock is shaped into an airplane member, the improvement wherein said stock is provided by a method comprising:

- (a) providing aluminous stock comprising:
  - (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;

5,213,639

29

- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock;
- (c) heating said stock within about 900° to 960° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating.

67. In a method wherein an aluminum alloy sheet is shaped into an airplane member, the improvement wherein said sheet is provided by a method comprising:

- (a) providing aluminous stock comprising:

- (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.8% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;

- (ii) a cladding thereon of a different aluminum alloy or aluminum;

- (b) hot rolling said stock, comprising rolling within 600° to 900° F., to a reduction in thickness of at least 40%;

- (c) heating said hot rolled stock within about 900° to 950° F. for more than 2 hours;

- (d) further hot rolling said stock comprising rolling within 550° to 900° F.;

- (e) solution heat treating at at least 900° F.;

- (f) natural aging.

68. In a method wherein an aluminum alloy material is shaped into a vehicular panel, the improvement wherein said material is provided by a method comprising:

- (a) providing aluminous stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;

- (b) hot rolling said stock;

- (c) heating said stock within about 900° to less than 970° F.;

- (d) further hot rolling said stock;

- (e) solution heat treating.

69. In a method wherein an aluminum alloy material is shaped into a vehicular panel, the improvement wherein said material is provided by a method comprising:

- (a) providing aluminous stock comprising:

- (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;

- (ii) a cladding thereon of a different aluminum alloy or aluminum;

- (b) hot rolling said stock;

- (c) heating said stock within 900° to 960° F.;

- (d) further hot rolling said stock;

- (e) solution heat treating;

- (f) cooling.

70. A product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said product having at least 5% improvement over 2024 alloy in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15ksi $\sqrt{\text{in}}$  or more, or in both said (a) and (b) properties.

30

71. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% iron, not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said product having a long transverse yield strength of 38 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said (a) and (b) properties.

72. An aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 10% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{IC}$  of at least 140 ksi $\sqrt{\text{in}}$ ; (c) a minimum T-L fracture toughness  $K_{app}$  of at least 8 ksi $\sqrt{\text{in}}$ .

73. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 38 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness at least equivalent to a  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  in a test panel around 16 inches wide; (c) a minimum T-L fracture toughness at least equivalent to a  $K_{app}$  of 80 ksi $\sqrt{\text{in}}$  in a test panel around 16 inches wide.

74. An aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.9 manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 39 ksi or more and a minimum T-L fracture toughness  $K_{IC}$  of at least 140 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

75. An aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.78% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 38 ksi or more and a minimum T-L fracture toughness  $K_{app}$  of 80 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

76. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements



5,213,639

31

and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said first alloy on one or more faces thereof, said sheet having a minimum long transverse yield strength of 38 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

77. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said first alloy on one or more faces thereof, said sheet having a minimum long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

78. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said first alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 10% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi $\sqrt{\text{in}}$ ; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi $\sqrt{\text{in}}$ .

79. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more and a minimum T-L fracture toughness  $K_{Ic}$  of 140 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

80. An aluminum alloy sheet product having a core of an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

81. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than

32

about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy having a long transverse yield strength of 39 ksi or more and exhibiting an average fatigue crack growth rate of not over  $1.4 \times 10^{-4}$  inch per cycle for growing a crack from about 1.7 inch to about 1 inch at a frequency of about 25 hertz and a stress ratio R of 0.1 and a substantially constant  $\Delta K$  of about 30 ksi $\sqrt{\text{in}}$  in an atmosphere of about 90% or more relative humidity.

82. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and exhibiting an average fatigue crack growth rate of not over  $1.4 \times 10^{-4}$  inch per cycle for growing a crack from about 1.7 inch to about 1 inch at a frequency of about 25 hertz and a stress ratio R of 0.1 and a substantially constant  $\Delta K$  of about 30 ksi $\sqrt{\text{in}}$  in an atmosphere of about 90% or more relative humidity.

83. A vehicular panel comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet product having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 10 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

84. Aircraft skin comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet product having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

85. Aircraft skin comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, less than 0.2% iron, less than 0.2% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet product having a minimum long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

86. Aircraft skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a

33

5,213,639

cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said aluminum product having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{app}$  of at least 80 ksi√in.

87. Aircraft skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 10% above one or more of the levels shown in FIGS. 8 or 9; (b) a T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a T-L fracture toughness  $K_{app}$  of at least 80 ksi√in.

88. Aircraft fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 15 ksi√in or more, or in both said properties.

89. Aircraft fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a T-L fracture toughness  $K_{app}$  of at least 80 ksi√in.

90. Aircraft fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 15 ksi√in or more, or in both said properties.

91. Aircraft fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.8% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different

34

from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a fatigue crack growth rate not greater than one or more of the levels shown in FIGS. 8 or 9; (b) a T-L fracture toughness  $K_{Ic}$  of at least 150 ksi√in; (c) a T-L fracture toughness  $K_{app}$  of at least 90 ksi√in.

92. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising fuselage skin comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 20 ksi√in or more, or in both said properties.

93. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 38 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 150 ksi√in; (c) a minimum T-L fracture toughness  $K_{app}$  of at least 90 ksi√in.

94. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 20 ksi√in or more, or in both said properties.

95. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a minimum long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 150



5,213,639

35

ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 90 ksi√in.

96. An aircraft having a member comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 20 ksi√in or more, or in both said properties.

97. An aircraft having a member comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, less than 0.2% iron, less than 0.2% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 150 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 90 ksi√in.

98. An aircraft having skin material comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, less than 0.2% iron, less than 0.2% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 20 ksi√in or more, or in both said properties.

99. An aircraft having skin material comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.12% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi√in.

100. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness

36

property, or (b) fatigue crack growth rate property at a  $\Delta K$  levels of 20 ksi√in or more, or in both said properties.

101. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.12% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi√in.

102. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 20 ksi√in or more, or in both said properties.

103. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.12% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi√in.

104. A method according to claim 64 wherein said recitation (h) comprises stretching.

105. A method according to claim 63 wherein said recitation (g) comprises stretching.

106. A method according to claim 64 wherein said recitation (h) comprises cold rolling.

107. A method according to claim 63 wherein said recitation (g) comprises cold rolling.

108. A method according to claim 64 wherein solution heat treating is preceded by cold rolling.

109. A method according to claim 63 wherein solution heat treating is preceded by cold rolling.

110. The method according to claim 1 wherein said stock further comprises a cladding on said alloy, said cladding being aluminum or an alloy thereof different than the said alloy.

111. The method according to claim 1 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.

37

5,213,639

112. The method according to claim 22 wherein after said solution heat treating, a forming or shaping operation is performed above room temperature.

113. The method according to claim 22 wherein after said solution heat treating, a forming or shaping operation is performed at a temperature of 200° F. or higher.

114. The method according to claim 22 wherein after said solution heat treating, a forming or shaping operation is performed at an artificial aging temperature above room temperature.

115. The method according to claim 22 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.

116. The method according to claim 28 wherein after said solution heat treating, a forming or shaping operation is performed above room temperature.

117. The method according to claim 28 wherein after said solution heat treating, a forming or shaping operation is performed at a temperature of 200° F. or higher.

118. The method according to claim 28 wherein after said solution heat treating, a forming or shaping operation is performed at an artificial aging temperature above room temperature.

119. The method according to claim 28 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.

120. The method according to claim 44 wherein after said solution heat treating, a forming or shaping operation is performed above room temperature.

121. The method according to claim 44 wherein after said solution heat treating, a forming or shaping operation is performed at a temperature of 200° F. or higher.

122. In the method according to claim 65 wherein said shaping operation is performed above room temperature.

123. In the method according to claim 65 wherein said shaping operation is performed at a temperature of 200° F. or higher.

124. A product produced by the method of claim 1, 5, 6, 8, 22, 23, 33, 38, 51, 63 or 64.

125. The product according to claim 71 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

126. The product according to claim 76 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

127. The product according to claim 77 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

128. An aircraft skin according to claim 84 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

129. An aircraft according to claim 100 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

130. The product according to claim 71 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

131. The product according to claim 76 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

132. The product according to claim 77 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

133. An aircraft skin according to claim 84 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

134. An aircraft fuselage, or fuselage portion, according to claim 94 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

135. An aircraft according to claim 100 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

136. The product according to claim 73 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

38

137. The product according to claim 74 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

138. The product according to claim 75 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

139. The product according to claim 78 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

140. The product according to claim 79 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

141. The product according to claim 80 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

142. An aircraft skin according to claim 86 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

143. An aircraft skin according to claim 87 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

144. An aircraft according to claim 97 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

145. An aircraft according to claim 101 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

146. The product according to claim 72 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

147. The product according to claim 73 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

148. The product according to claim 74 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

149. The product according to claim 75 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

150. The product according to claim 78 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

151. An aircraft skin according to claim 87 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

152. An aircraft fuselage skin according to claim 89 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

153. An aircraft fuselage skin according to claim 91 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

5,213,639

154. An aircraft fuselage, or fuselage portion, according to claim 93 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

155 An aircraft according to claim 101 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more

156. The product according to claim 72 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

157. The product according to claim 73 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

158. The product according to claim 74 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25$  ksi $\sqrt{\text{in}}$  or more.

159. The product according to claim 75 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

160. The product according to claim 78 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

161. An aircraft skin according to claim 86 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

162. An aircraft skin according to claim 87 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

163. An aircraft fuselage skin according to claim 89 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

164. An aircraft fuselage skin according to claim 91 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

165. An aircraft fuselage, or fuselage portion, according to claim 93 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25$  ksi $\sqrt{\text{in}}$  or more.

166. An aircraft according to claim 101 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

167. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

168. The product according to claim 78 wherein said product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

169. An aircraft skin according to claim 86 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

170. An aircraft skin according to claim 87 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

189. An aircraft fuselage skin according to claim 88 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 150 ksi $\sqrt{\text{in}}$  or more.

190. An aircraft according to claim 101 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 150 ksi $\sqrt{\text{in}}$  or more.

191. An aircraft according to claim 103 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 150 ksi $\sqrt{\text{in}}$  or more.

192. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi $\sqrt{\text{in}}$  or more.



5,213,639

41

193. An aircraft skin according to claim 86 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi√in or more.

194. An aircraft skin according to claim 87 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi√in or more.

195. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi√in or more.

196. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

197. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

198. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

199. The product according to claim 78 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

200. The product according to claim 80 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

201. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

202. An aircraft according to claim 101 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

203. An aircraft according to claim 103 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

204. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

205. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

206. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

207. The product according to claim 78 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

208. The product according to claim 80 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

209. An aircraft skin according to claim 86 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

210. An aircraft skin according to claim 87 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

211. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

212. An aircraft according to claim 101 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

42

213. An aircraft according to claim 103 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

214. The product according to claim 73 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

215. The product according to claim 79 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

216. The product according to claim 80 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

217. An aircraft skin according to claim 84 wherein said fatigue crack growth rate level is at  $\Delta K=20$  ksi√in or more.

218. An aircraft skin according to claim 86 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

219. An aircraft skin according to claim 87 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

220. An aircraft fuselage skin according to claim 89 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

221. An aircraft fuselage skin according to claim 91 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

222. An aircraft according to claim 101 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=20$  ksi√in or more.

223. The product according to claim 78 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

224. The product according to claim 79 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

225. The product according to claim 80 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

226. An aircraft skin according to claim 86 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

227. An aircraft skin according to claim 87 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

228. An aircraft skin according to claim 89 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

229. An aircraft fuselage skin according to claim 91 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

230. An aircraft according to claim 101 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K=25$  ksi√in or more.

231. The product according to claim 81 wherein said average fatigue crack growth rate is not over  $1.25 \times 10^{-4}$  inch per cycle.

232. The product according to claim 82 wherein said average fatigue crack growth rate is not over  $1.25 \times 10^{-4}$  inch per cycle.

UNITED STATES PATENT AND TRADEMARK OFFICE  
CERTIFICATE OF CORRECTION

PATENT NO. : 5,213,639

DATED : May 25, 1993

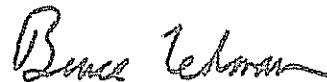
INVENTOR(S) : Edward L. Colvin et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 14, line 14	Before "21.4 x 10 <sup>-5</sup> " insert --at--
Col. 30, line 23, Claim 72	Change "8 ksi $\sqrt{\text{in}}$ " to --80 $\sqrt{\text{ksi in}}$ --
Col. 31, line 22, Claim 77	Before "ksi $\sqrt{\text{in}}$ " insert --15--

Signed and Sealed this  
Fifth Day of July, 1994

Attest:



BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

STATE OF NEW YORK     )  
  ) SS:  
COUNTY OF NEW YORK    )

Solange C. Ruff, being duly sworn, deposes and declares:

That she is a freelance translator and interpreter, 111 West 16<sup>th</sup> Street,  
Apt 6H, New York, New York 10011;

That she is fully conversant in the French and English languages;

That she translated the attached documents:

SERVICE OF A SUMMONS AND COMPLAINT ON ALCAN  
RHENALU AND RECORD OF SERVICE

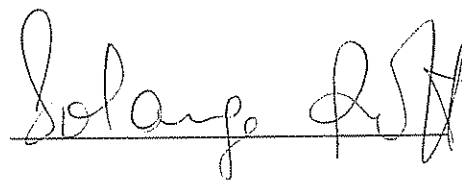
into English;

and that the English translation is, to her best knowledge and belief, a true  
and correct rendering of the original text in the French language.

Sworn to before me this

29<sup>th</sup> day of June, 2006.

  
Notary Public



KEITH S. KAPLAN  
Notary Public, State of New York  
No. 01KA6062463  
Qualified in New York County  
Commission Expires Aug. 6, 2009

STATE OF NEW YORK )

) SS:

COUNTY OF NEW YORK )

Solange C. Ruff, being duly sworn, deposes and declares:

That she is a freelance translator and interpreter, 111 West 16<sup>th</sup> Street,  
Apt 6H, New York, New York 10011;

That she is fully conversant in the French and English languages;

That she translated the attached documents:

ALCOA COMPLAINT AND RELATED DOCUMENTS

into French;

and that the French translation is, to her best knowledge and belief, a true and correct rendering of the original text in the English language.

Sworn to before me this

14<sup>th</sup> day of June, 1906

Shirley Rodriguez  
Notary Public

Notary Public

Maey RTH

**CHARISSE Y. RODRIGUEZ**  
Notary Public, State of New York  
No. 01RO6145128  
Qualified in New York County  
Commission Expires May 1, 2010

TRIBUNAL FÉDÉRAL DE PREMIÈRE INSTANCE  
DU DISTRICT DU DELAWARE

ALCOA, INC.,

le Demandeur,

contre

ALCAN, INC., une société de droit canadien,  
ALCAN CORP., une société constituée dans l'État du  
Texas, ALCAN CORP., une société constituée dans l'État  
du Delaware, PECHINEY, S.A., une société de droit  
français, ALCAN RHENALU, une société de droit  
français, ALCAN PECHINEY CORP., une société  
constituée dans l'État du Texas, PECHINEY METALS,  
LLC, une société à responsabilité limitée incorporée dans  
l'État du Delaware, ALCAN ROLLED PRODUCTS –  
RAVENSWOOD, LLC, une société à responsabilité  
limitée incorporée dans l'État du Delaware,

C.A. No. [tampon: 06 – 383]

les Défendeurs

POUR: Alcan-Rhenalu  
c/o Secretary of State, State of Delaware [Secrétaire d'État, État du Delaware]  
Division of Corporations – Townsend Building [Service des Sociétés]  
Duke of York Street  
Dover, Delaware 19901

PAR LES PRÉSENTES, VOUS ÊTES CITÉ À COMPARAÎTRE et à signifier au CONSEIL  
DU DEMANDEUR

**Jeffrey L. Moyer, Esquire**  
**Richards, Layton & Finger**  
**One Rodney Square**  
**Wilmington, DE 19899**  
**(302) 651-7700**

une réponse à la plainte qui vous est signifiée par les présentes dans un délai de vingt (20) jours  
consécutifs suivants la signification de cette convocation, hors le jour de la signification. Faute de quoi,  
un jugement par défaut sera rendu contre vous selon le remède requis dans la plainte. Toute réponse que  
vous aurez signifié aux parties de cette action en justice doit être déposée auprès du greffier de ce  
Tribunal dans un délai raisonnable suivant la notification.

[TAMPON] PETER T. DALLEO  
GREFFIER

[dateur] 13 JUIN 2006  
DATE

[signature]  
LE GREFFIER SUPPLÉANT



<b>RETOUR DE LA SIGNIFICATION</b>		
La signification de la citation à comparaître et de la plainte a été faite par le soussigné <sup>1</sup>	Date 13/6/06	
NOM DU HUISSIER (Imprimé) GRANVILLE MORRIS	Titre HUISSIER SPECIALISÉ	
<i>Veuillez cocher l'une des cases ci-dessous pour indiquer la méthode de signification utilisée</i>		
<div style="margin-bottom: 10px;"> <input type="checkbox"/> Signifié personnellement au défendeur. Lieu de signification: _____            _____         </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Copie des documents a été remise au domicile du défendeur ou à sa demeure habituelle à une personne d'un âge et d'une discrétion appropriés qui y résidait.            Nom de la personne à laquelle la citation à comparaître et de la plainte ont été remises:            _____         </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Renvoyé sans avoir été exécuté: _____            _____         </div> <div> <input checked="" type="checkbox"/> Autre (préciser): SIGNIFIÉ: <u>ALCAN-RHENALU C/O LE SECRETAIRE D'ÉTAT DU DELAWARE DOVER, DELAWARE COPIES ACCEPTÉES PAR NANCY POE (AGENT DE PROCÉDURE</u> </div>		
<b>DROITS DE SIGNIFICATION</b>		
Déplacement	Signification	Total
<b>DÉCLARATION DE L'HUISSIER</b>		
<p>Je déclare sous serment sous peine de parjure conformément aux lois des États-Unis d'Amérique que l'information ci-dessus concernant le Retour de la Signification et la Déclaration des Droits de Signification est exact.</p> <div style="display: flex; justify-content: space-between; margin-top: 20px;"> <div style="width: 45%;"> <p>Fait le <u>13 juin, 2006</u>  <i>Date</i></p> </div> <div style="width: 45%; text-align: right;"> <p>[signature]</p> <p>_____  <i>Signature du huissier</i>            BRANDYWINE PROCESS SERVERS, LTD            P.O. BOX 1360            WILMINGTON, DE 19899-1360            302-475-2600</p> </div> </div>		

<sup>1</sup> Voir la Règle 4 du Règlement fédéral de Procédure civile pour déterminer quels sont les personnes autorisées à signifier une citation à comparaître

## PAGE COUVERTURE EN MATIÈRE CIVILE

[tampon] 06-383

JS44

(Modif. 12/96)

La page couverture JS44 et l'information qui y est contenue ne vaut ni dépôt ni signification d'actes de procédure ou d'autres documents exigés par la loi, sauf disposition contraire prévue par les règlements des tribunaux locaux. Ce formulaire a été approuvé par la Conférence Judiciaire des États-Unis en septembre 1974 et il doit être fourni pour être utilisé par le Greffier afin d'établir la feuille du registre d'audiences entendues en matières civiles à inclure dans le dossier (VOIR INSTRUCTIONS AU VERSO)

## I. (a) DEMANDEUR

Alcoa Inc.

(b) COMTÉ DE RÉSIDENCE DU PREMIER DEMANDEUR  
NOMMÉ DANS LA DEMANDE NEW YORK  
(SAUF SI LE DEMANDEUR EST LE GOUVERNEMENT DES ÉTATS-UNIS)

## DÉFENDEUR

Voir Pièce 1 jointe

COMTÉ DE RÉSIDENCE DU PREMIER DÉFENDEUR NOMMÉ  
DANS LA DEMANDE

(SEULEMENT SI LE DEMANDEUR EST LE GOUVERNEMENT DES ÉTATS-UNIS)  
REMARQUE : POUR LES EXPROPRIATIONS DE TERRAIN UTILISER LE LIEU DE  
L'ÉTENDUE DE TERRAIN CONCERNÉ

## (c) AVOCATS (NOM DU CABINET, ADRESSE, NUMÉRO DE TÉLÉPHONE)

Jeffrey L. Moyer  
Richards, Layton & Finger  
One Rodney Square - PO Box 551  
Wilmington, DE 19899  
(302) 651-7700

AVOCATS (SI CONNUS)

## II. DÉTERMINATION DE LA COMPÉTENCE JURIDICTIONNELLE

(cocher une seule case)

- ☐ 1 Gouvernement des États-Unis Demandeur ☐ 3 Matière fédérale (le Gouvernement des EU n'est pas une partie)
- ☐ 2 Gouvernement des États-Unis ☐ 4 Diversité (indiquer la citoyenneté des parties sous III)

## III CITOYENNETÉ DES PRINCIPALES PARTIES (cocher une case pour le demandeur et une case pour le défendeur)

DEM DEF

DEM DEF

- Citoyen de cet État ☐ 1 ☐ 1 Société constituée dans cet État ou y ayant son principal établissement ☐ 4 ☐ 4
- Citoyen d'un autre État ☐ 2 ☐ 2 Société constituée dans un autre État et y ayant son principal établissement ☐ 5 ☐ 5
- Citoyen ou sujet d'un pays étranger ☐ 3 ☐ 3 Nation étrangère ☐ 6 ☐ 6

## VI. [sic] ORIGINE (COCHER UNE SEULE CASE)

- ☒ 1 Instance originale ☐ 2 Tribunal d'état dessaisi de l'affaire ☐ 3 Renvoi par la Cour d'appel réintroduite ou rouverte ☐ 4 Instance depuis un autre district (préciser) ☐ 5 Instance transférée depuis un autre district (préciser) ☐ 6 Litige concernant plusieurs districts ☐ Appel du jugement de première instance interjeté devant le Juge de district

## V. NATURE DE L'ACTION EN JUSTICE (COCHER UNE SEULE CASE)

CONTRATS	RESPONSABILITÉ CIVILE	DÉCHÉANCE/SANCTIONS	FAILLITE	AUTRES LOIS
<input type="checkbox"/> 110 Assurance <input type="checkbox"/> 120 Droit maritime <input type="checkbox"/> 130 Loi Miller <input type="checkbox"/> 140 Instr. négociable <input type="checkbox"/> 150 Recouvrement de versements excédentaires et exécution de jugement <input type="checkbox"/> 151 Loi Medicare <input type="checkbox"/> 152 Recouvrement de prêt étudiant en défaut (hors anciens combattants) <input type="checkbox"/> 153 Recouvrement de versements excédentaires sur avantages anciens combattants <input type="checkbox"/> 160 Litiges actionnaires <input type="checkbox"/> 190 Autres contrats <input type="checkbox"/> 195 Responsabilité produits sous contrat	<b>PRÉJUDICE PERSONNEL</b> <input type="checkbox"/> 310 Avion <input type="checkbox"/> 315 Responsabilité produits avion <input type="checkbox"/> 320 Agression, diffamation écrite ou orale <input type="checkbox"/> 330 Responsabilité des employeurs fédéraux <input type="checkbox"/> 340 Droit maritime <input type="checkbox"/> 345 Responsabilité produits maritime <input type="checkbox"/> 350 Automobile <input type="checkbox"/> 355 Responsabilité produits automobile <input type="checkbox"/> 360 Autres préjudices personnels	<input type="checkbox"/> 362 Préjudice personnel - faute médicale <input type="checkbox"/> 365 Préjudice personnel - Responsabilité produits <input type="checkbox"/> 368 Amiante - préjudice personnel - Responsabilité produits <b>BIENS PERSONNELS</b> <input type="checkbox"/> 370 Autres fraudes <input type="checkbox"/> 371 Transparence en matière de prêts <input type="checkbox"/> 380 Autres dommages matériels <input type="checkbox"/> 385 Dommages matériels responsabilité produits	<input type="checkbox"/> 610 Agriculture <input type="checkbox"/> 620 Autres aliments et médicaments <input type="checkbox"/> 625 Saisie de propriété en matière de drogues 21 USC [Code des États-Unis] 881 <input type="checkbox"/> 630 Lois sur les boissons alcooliques <input type="checkbox"/> 640 Transport ferroviaire et routier <input type="checkbox"/> 650 Regl. transport aérien <input type="checkbox"/> 660 Santé et sécurité au travail <input type="checkbox"/> 690 Autres	<input type="checkbox"/> 422 Recours 28 USC 158 <input type="checkbox"/> 423 Désistement 28 USC 157 <b>DROITS DE PROPRIÉTÉ</b> <input type="checkbox"/> 820 Droits d'auteur <input type="checkbox"/> X 830 Brevets <input type="checkbox"/> 840 Marques de commerce <b>SECURITÉ SOCIALE</b> <input type="checkbox"/> 861 HIA (Loi sur l'assurance santé) (135911) <input type="checkbox"/> 862 Black Lung [Avantages payés aux trav. du secteur minier] (923) <input type="checkbox"/> 863 DIWC/DIWW [Pensions d'invalidité/de veuf veuve] (405 (g)) <input type="checkbox"/> 864 SSDI [Prestations d'incapacité] Titre XVI <input type="checkbox"/> 865 RSI [retraite et rente conjoint] (405 (g)) <b>LITIGES FÉDÉRAUX EN MATIÈRES FISCALES</b> <input type="checkbox"/> 870 Impôts - (le Gov. des EU est demandeur ou défendeur) <input type="checkbox"/> 871 IRS [Service Fiscal] - Tiers 26 USC 7609
<b>BIEN RÉELS</b> <input type="checkbox"/> 210 Expropriation de terrain <input type="checkbox"/> 220 Forclusion <input type="checkbox"/> 230 Bail et expulsion <input type="checkbox"/> 240 Délit de nuisance et intrusion <input type="checkbox"/> 245 Délit responsabilité produits <input type="checkbox"/> 290 Tous autres biens réels	<b>DROITS CIVILS</b> <input type="checkbox"/> 441 Suffrage <input type="checkbox"/> 442 Travail <input type="checkbox"/> 443 Habitation/logement <input type="checkbox"/> 444 Assistance sociale <input type="checkbox"/> 440 Autres droits civils	<b>REQUÊTES DE PRISONNIERS</b> <input type="checkbox"/> 510 Requête de casser un jugement par habens corpus : <input type="checkbox"/> 530 Ordonnances générales <input type="checkbox"/> 535 Peine de mort <input type="checkbox"/> 540 Mandamus et autres <input type="checkbox"/> 550 Droits civils <input type="checkbox"/> 555 Conditions de prison		[tampon] DEPOSE GREFFIER DU TRIBUNAL FÉDÉRAL DE PREMIÈRE INSTANCE DU DISTRICT DELAWARE 2006 JUN 13 3:34

VI. MOTIF DE L'ACTION EN JUSTICE (INDIQUER LA LÉGISLATION CIVILE EN VERTU DE LAQUELLE CETTE ACTION EST INTRODUE ET EXPOSER BRIÈVEMENT PAR ÉCRIT LE MOTIF NE PAS FAIRE RÉFÉRENCE AUX LOIS EN MATIÈRE DE COMPÉTENCE JURIDICTIONNELLE SAUF DANS LES CAS DE DIVERSITÉ.) Action en contrefaçon de brevet en vertu de la loi 35 USC §271)

VII. REQUIS DANS LA DEMANDE : COCHER SI CLASS ACTION RECIAMATION S COCHER OUI seulement si requis dans la demande :  
☐ en vertu de la FRCP [règle de procédures civiles fédérale] 23 JURY REQUIS : OUI ☒ NON

## VIII. ÉVENTUELLES ACTION(S) (Voir instructions)

CONNEXE(S)

Juge Sue L. Robinson

No. de l'action dans le registre d'audiences : 99-301-SLR

DATE Le 13 juin 2006 SIGNATURE DE L'AVOCAT INSCRIT AU DOSSIER  
 (Gregory E. Stohlman) [signature]

À USAGE INTERNE SEULEMENT

REÇU NO. \_\_\_\_\_ MONTANT \_\_\_\_\_ APPLICATION D'IFP [formulaire d'exemption de frais] \_\_\_\_\_ JUGE \_\_\_\_\_ MAGISTRAT \_\_\_\_\_

INSTRUCTIONS À L'USAGE DES AVOCATS À SUIVRE POUR REMPLIR LE FORMULAIRE PAGE COUVERTURE JS-44

RLF1-3025218

## Règles applicables aux pages couverture en matière civile

La page couverture JS44 et l'information qui y est contenue ne vaut ni dépôt ni signification d'actes de procédure ou d'autres documents exigés par la loi, sauf disposition contraire prévue par les règlements des tribunaux locaux. Ce formulaire a été approuvé par la Conférence Judiciaire des États-Unis en septembre 1974 et il doit être fourni pour être utilisé par le Greffier afin d'établir la feuille du registre d'audiences entendues en matières civiles à inclure dans le dossier. Par conséquent, une page couverture en matière civile doit être transmise au Greffier avec chaque plainte civile déposée. L'avocat déposant une action doit remplir le formulaire comme suit :

**I. (a) Demandeurs – Défendeurs.** Indiquer les noms (nom, prénom, initiale du second prénom) du demandeur et du défendeur. Si le demandeur ou le défendeur est un organisme gouvernemental, n'utiliser que le nom entier ou des abréviations standard. Si le demandeur ou le défendeur est fonctionnaire d'un organisme gouvernemental, identifier d'abord l'organisme et ensuite le fonctionnaire en indiquant son nom et fonction.

(b) **Comté de résidence.** Pour chaque action civile déposée, sauf dans les cas où le Gouvernement des États-Unis est demandeur, indiquer le nom du comté où réside le premier demandeur nommé dans la demande au moment du dépôt. Pour les actions dans lesquelles le Gouvernement des États-Unis est demandeur, indiquer le nom du comté où réside le premier défendeur nommé dans la demande. (REMARQUE : pour les expropriations de terrain, le comté de résidence du "défendeur" est le lieu de l'étendue de terrain concerné.)

(c) **Avocats.** Indiquer le nom du cabinet, l'adresse, le numéro de téléphone et l'avocat inscrit au dossier. S'il y a plusieurs avocats, les énumérer en annexe et inclure dans cette section la mention "(voir annexe)".

**II. Compétence juridictionnelle.** La détermination de la compétence juridictionnelle est prévue à la Règle 8(a) du règlement FRCP selon laquelle la compétence juridictionnelle doit être indiquée dans les actes de procédures. Cocher une des cases. S'il existe plusieurs compétences juridictionnelles pouvant servir de base suivre l'ordre de priorité ci-dessous :

Gouvernement des États-Unis demandeur (1) La compétence se base sur 28 USC 1345 et 1348. Inclure ici les actions en justice introduites par des organismes ou fonctionnaires des États-Unis.

Gouvernement des États-Unis défendeur (2) Cocher cette case pour les actions introduites par un demandeur à l'encontre des États-Unis, ses fonctionnaires ou ses organismes.

Matière fédérale (3) Vise les actions en vertu du 28 USC 1331, dans lesquelles la compétence est fondée sur la Constitution des États-Unis, une modification de la Constitution, une loi du Congrès ou un traité des États-Unis. Dans les cas dans lesquels les États-Unis ont la qualité de partie à l'action, le code EU demandeur ou défendeur prévaut et les cases 1 et 2 doivent être cochées.

Diversité de citoyenneté (4) Vise les actions en vertu du 28 USC 1332, dans lesquelles les parties sont des citoyens de différents pays. Si la case 4 est cochée, il faut cocher la citoyenneté des différentes parties. (Voir Section III ci-dessous – les actions en matière fédérale prévalent sur les actions de diversité.)

**III. Résidence (citoyenneté) des principales parties.** Cette partie du formulaire JS 44 doit être remplie si la diversité de citoyenneté a été indiquée plus haut. Marquer cette section pour chacune des parties principales à l'action.

**IV. [sic] Motif de l'action.** Fournir la loi civile directement liée au motif de l'action et une brève description du motif.

**V. Nature de l'action en justice.** Cocher la case appropriée. Si la nature de l'action ne peut pas être déterminée, s'assurer que le motif de l'action indiqué à la Section IV ci-dessus est suffisant pour que le greffier suppléant ou les commis statisticiens du Bureau Administratif puissent déterminer la nature de l'action en justice. Si le motif correspond à plusieurs natures d'action en justice, élire celle qui est la plus définitive.

**VI. [sic] Origine.** Cocher l'une des sept cases.

Instance originale (1) Actions introduites dans les cours de district des États-Unis.

Tribunal d'état dessaisi de l'affaire (2) Un tribunal d'état peut être dessaisi d'une affaire introduite dans un tel tribunal et l'affaire transférée aux tribunaux de district en vertu du Titre 28 de l'USC, Section 1441. Cocher cette case si la demande de dessaisissement a été admise.

Renvoi par la Cour d'appel (3) Cocher cette case si l'action en justice a été renvoyée aux tribunaux de district pour y donner suite. Utiliser la date du renvoi comme date de dépôt.

Instance réintroduite ou rouverte (4) Cocher cette case si l'action en justice a été réintroduite ou rouverte dans les tribunaux de district. Utiliser la date de réintroduction comme date de dépôt.

Instance transférée depuis un autre district (5) Applicable aux actions transférées en vertu du Titre 28 USC Section 1404 (a). Ne pas utiliser pour les transferts à l'intérieur d'un district ou pour les transferts dans le cadre de litiges concernant plusieurs districts.

Litige concernant plusieurs districts (6) Cocher cette case si un litige concernant plusieurs districts est transférée au district soumis à l'autorité du Titre 28 USC Section 1407. Ne pas cocher (5) ci-dessus si cette case est cochée.

Appel du jugement de première instance interjeté devant le Juge de district (7) Cocher cette case pour les appels des jugements de premières instance.

**VII. Requis dans la demande.** Class action [recours collectif]. Cocher cette case si l'action introduite est une Class action en vertu de la Règle 23 du FRCP.

Réclamations. Porter ici le montant en dollars (en milliers de dollars) réclamé ou indiquer toute autre réclamation telle qu'une injonction provisoire.

Jury requis. Cocher la case appropriée pour indiquer si un jury est requis ou non.

**VIII. Actions connexes.** Cette section du formulaire JS 44 sert à faire référence à des causes connexes en instance, le cas échéant. S'il existe des causes en instances connexes, inclure les numéros de ces causes dans les registres d'audiences et les noms des juges correspondant à de telles causes.

**Date et signature de l'avocat.** Dater et signer la page couverture en matière civile.

(modif. 07/89)

**Pièce 1**

**Défendeurs**

Alcan Inc.

Alcan Corp.

Alcan Corp.

Pechiney, S.A.

Alcan-Rhenalu

Alcan Pechiney Corp.

Pechiney Metals LLC

Alcan Rolled Products - Ravenswood LLC

**TRIBUNAL FÉDÉRAL DE PREMIÈRE INSTANCE  
DU DISTRICT DU DELAWARE**

ALCOA, INC.,

le Demandeur,

contre

ALCAN, INC., une société de droit canadien,  
ALCAN CORP., une société constituée dans l'État du  
Texas, ALCAN CORP., une société constituée dans l'État  
du Delaware, PECHINEY, S.A., une société de droit  
français, ALCAN RHENALU, une société de droit  
français, ALCAN PECHINEY CORP., une société  
constituée dans l'État du Texas, PECHINEY METALS,  
LLC, une société à responsabilité limitée incorporée dans  
l'État du Delaware, ALCAN ROLLED PRODUCTS –  
RAVENSWOOD, LLC, une société à responsabilité  
limitée incorporée dans l'État du Delaware,

les Défendeurs

[tampon]

DEPOSE

GREFFIER DU TRIBUNAL FEDERAL DE  
PREMIÈRE INSTANCE DU DISTRICT DU  
DELAWARE

2006 JUIN 13 8:57

Litige No.

**RÈGLE 7.1 DOCUMENT D'INFORMATION RELATIF À UNE SOCIÉTÉ**

Conformément à la Règle 7.1 du Règlement fédéral de Procédure civile, Alcoa, Inc.

certifie par les présentes n'avoir aucune société mère. Aucune société anonyme ne détient 10%  
ou plus des actions de la société.

[signature]

Date: le 13 juin 2006

Frederick L. Cottrell, III (#2555)

cottrell@rlf.com

Jeffrey L. Moyer (#3309)

moyer@rlf.com

Gregory E. Stuhlman (#4765)

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RICHARDS, LAYTON & FINGER

One Rodney Square

P.O. Box 551

Wilmington, DE 19899

(302) 651-7700

*Conseils du Demandeur Alcoa, Inc.*



TRIBUNAL FÉDÉRAL DE PREMIÈRE INSTANCE  
DU DISTRICT DU DELAWARE

ALCOA, INC.,

Demandeur,

contre

ALCAN, INC., une société de droit canadien,  
ALCAN CORP., une société constituée dans  
l'État du Texas, ALCAN CORP., une société  
constituée dans l'État du Delaware, PECHINEY,  
S.A., une société de droit français, ALCAN  
RHENALU, une société de droit français,  
ALCAN PECHINEY CORP., une société  
constituée dans l'État du Texas, PECHINEY  
METALS, LLC, une société à responsabilité  
limitée incorporée dans l'État du Delaware,  
ALCAN ROLLED PRODUCTS –  
RAVENSWOOD, LLC, une société à  
responsabilité limitée incorporée dans l'État du  
Delaware,

les Défendeurs

[tampon]

DEPOSE

GREFFIER DU TRIBUNAL FÉDÉRAL DE  
PREMIÈRE INSTANCE DU DISTRICT DU  
DELAWARE

2006 JUIN 13 8:57

C.A. No.

[tampon] 06-383

PLAINTÉ

Le Demandeur, Alcoa Inc. ("Alcoa"), représenté par ses avocats, en toute connaissance de ses propres actions et se reposant sur des informations et des convictions en ce qui concerne d'autres affaires, déclare ce qui suit :

Nature de la Plainte

1. La présente action en justice est motivée par les travaux entrepris par Pechiney, S.A. et Alcan, Inc. ("Alcan"), les successeurs de Pechiney, S.A. et leur filiale à 100%, Pechiney Rhenalu (collectivement, "Pechiney"), visant à répliquer des produits brevetés à base d'alliage d'aluminium qui ont fait l'objet d'un succès commercial considérable pour Alcoa. Il y a à peine quatre ans, ce Tribunal avait débouté les efforts de Pechiney visant à annuler le brevet d'Alcoa aux États-Unis, United States Patent No. 5,213,639 (le "brevet '639"), en statuant qu'il y avait effectivement violation du brevet de la part de Pechiney en l'objet d'un alliage d'aluminium

élaboré par Pechiney à son centre de recherche de Voreppe, en France, et fabriqué à son usine de laminés d'Issoire, en France également. Cf. Pechiney Rhenalu v. Alcoa, Inc., 224 F Supp. 2d 773 (D. Del. 2002).

2. Alcan, qui avait acquis Pechiney en 2004, commercialise actuellement un autre alliage, essentiellement équivalent, qui a été mis au point par les mêmes ingénieurs et techniciens travaillant au même centre de recherche de Voreppe et fabriqué à la même usine de laminés d'Issoire. Alcan a indiqué son intention de mettre des produits incorporant l'alliage de contrefaçon sur le marché aux États-Unis, et ce dans des délais très brefs, et de les offrir également à des fabricants étrangers qui pourraient vraisemblablement importer des produits comportant cet alliage aux États-Unis, en violation de la loi américaine sur les brevets 35 U.S.C. §§ 271(a) et (b).

3. Pour ces faits, Alcoa demande un jugement déclaratif et une mesure injonctive au titre du brevet '639.

#### Les Parties, la Compétence et la Juridiction

4. Alcoa, Inc. est une société constituée conformément aux lois du Commonwealth de Pennsylvania. Son siège social est situé 390 Park Avenue, New York, NY 10022-4608. Alcoa fabrique notamment des produits à base d'alliage d'aluminium destinés à l'aéronautique qu'elle vend aux États-Unis et dans le monde entier.

5. Alcan, Inc. est une société de droit canadien ayant son siège à 1188 Sherbrooke Street West, Montréal, Québec H3A 3G2. Alcan fabrique notamment des produits à base d'aluminium et d'alliage d'aluminium destinés à l'aéronautique qu'elle vend dans le monde entier.

6. Une part considérable du chiffre d'affaires d'Alcan provient de la vente de produits et de services utilisés aux États-Unis, y compris dans l'État du Delaware. Alcan poursuit ses activités sociales de façon suivie dans l'État du Delaware notamment par le biais de ses nombreuses filiales incorporées dans l'État.

7. Alcan poursuit ses activités aux États-Unis et dans le monde entier à travers un réseau complexe de sociétés croisées, tel que décrit plus bas.

8. Les activités d'Alcan aux États-Unis sont assurées par Alcan Corp, une société détenue à 100% et constituée dans l'État du Texas, ayant son siège au 6060 Parkland Boulevard, Mayfield Heights, OH 44124.

9. Parmi les filiales d'Alcan constituées dans l'État du Delaware se trouve une société, également dénommée Alcan Corp, ayant son siège au 8770 West Bryn Mawr, Chicago, IL 60651.

10. La société Alcan Corp. du Texas opère à travers de nombreuses filiales contrôlées à cent pour cent qui, elles-mêmes, poursuivent leurs activités à travers d'autres filiales. Les filiales d'Alcan Corp. comprennent, notamment, Alcan Pechiney Corp. qui opère à travers une filiale, Pechiney Metals LLC, laquelle opère à travers une autre filiale Alcan Rolled Products – Ravenswood LLC.

11. Alcan Pechiney Corp., une filiale à 100% d'Alcan Corp., est une société constituée au Texas ayant son siège social au 6060 Parkland Boulevard, Mayfield Heights, OH 44124.

12. Pechiney Metals LLC, une filiale à 100% d'Alcan Corp., est une société à responsabilité limitée constituée dans le Delaware. Pechiney Metals LLC succède à Pechiney Metals Corp. dont elle a repris les intérêts et qui était une filiale de Pechiney avant l'acquisition de Pechiney par Alcan.

13. Alcan Rolled Products – Ravenswood, LLC ("Alcan Rolled Products"), une filiale à 100% de Pechiney Metals LLC, est une société à responsabilité limitée constituée dans le Delaware qui exploite l'ancienne usine de laminés de Pechiney à Ravenswood, dans l'État de West Virginia. Alcan Rolled Products succède à Pechiney Rolled Products, LLC dont elle a repris les intérêts et qui était une filiale de Pechiney

Metal Corp. avant l'acquisition de Pechiney par Alcan. L'usine de Ravenswood qui fabrique des produits à base d'aluminium et d'alliage d'aluminium destinés à l'industrie aéronautique est une des plus grandes usines de laminés au monde. Elle a la capacité de fabriquer des tôles de fuselage et d'autres produits qui incorporent l'alliage le plus récent en vente aux États-Unis et dans le monde entier et qui fait l'objet des poursuites en contrefaçon.

14. En décembre 2003, Alcan acquit le contrôle de Pechiney, une société française ayant son siège au 7 place du Chancelier Adenauer, 75218 Paris Cedex 16 (France). Au mois de février 2004, Pechiney, fabricant de produits à base d'aluminium et d'alliage d'aluminium, devint une filiale détenue à 100% par Alcan.

15. Alcan Rhenalu est une filiale détenue à cent pour cent par Pechiney S.A., laquelle fabrique des produits à base d'aluminium et d'alliage d'aluminium destinés à l'industrie aéronautique. Alcan Rhenalu, une société anonyme de droit français, succède à Pechiney Rhenalu dont elle a repris les intérêts. Elle a son siège au 7 place du Chancelier Adenauer, 75218 Paris Cedex 16 (France).

16. Le pôle Engineered Products d'Alcan comprenant l'activité aéronautique a désormais son siège au 7 place du Chancelier Adenauer, 75218 Paris Cedex 16 (France). Le centre de recherche du pôle comprend l'usine de Voreppe (France) où Pechiney élaborait l'alliage de contrefaçon qui fait l'objet des poursuites en contrefaçon précédentes. Ses usines de fabrication comprennent notamment l'usine de laminés d'Issoire, où cet alliage objet des poursuites était fabriqué.

17. Le dernier alliage de contrefaçon d'Alcan a été fabriqué à l'usine de Voreppe par les mêmes ingénieurs et techniciens qui avaient mis au point l'alliage qui avait enfreint le brevet précédemment. L'alliage de contrefaçon est fabriqué à la même usine de laminés d'Issoire (France), où l'alliage en question avait été fabriqué.

18. Le Tribunal a la compétence *ratione materiae* pour connaître les griefs soutenus aux présentes en vertu de la loi des États-Unis 28 U.S.C. §§ 1331, 1338(a), 2201 et 2002. Le District est la juridiction appropriée en vertu de la loi 28 U.S.C. §§ 1391 et 1400.

19. Péchiney avait précédemment saisi la juridiction du présent Tribunal en la matière, requérant une déclaration selon laquelle son alliage essentiellement identique n'enfreignait pas les revendications du brevet '639 et que ce brevet était sans validité. Alcan relève de la juridiction de ce Tribunal en tant que successeur et ayant-repris les intérêts de Péchiney, ainsi qu'au titre des activités poursuivies par Alcan dans l'État du Delaware.

20. Le comportement d'enfreinte au brevet de chacune des filiales d'Alcan, telles que décrites ci-dessus, les rend complices dans cette affaire de contrefaçon qui fait l'objet de la présente plainte.

#### Le brevet '639 et l'enfreinte précédente de Péchiney

21. Le 25 mai 1993, le Bureau américain des Brevets et des Marques de Commerce délivre le brevet '639 intitulé "Damage Tolerant Aluminum Alloy Products Useful for Aircraft Applications Such as Skin," [produits en alliage d'aluminium présentant une tolérance aux dommages, utilisables pour application aéronautique tel que les tôles de fuselage] au nom d'Alcoa. Un exemplaire du brevet '639 est joint en Annexe A.

22. Le brevet '639 révèle et revendique certains produits en alliage d'aluminium, ainsi que leurs méthodes de fabrication, qui s'avèrent particulièrement utiles dans la construction de fuselage pour avions commerciaux. Comparé aux produits fabriqués à partir des alliages d'aluminium classiques utilisés depuis les années 1950, le produit présentait une caractéristique de "ténacité" améliorée – la capacité de résister à la progression catastrophique d'une fissure – et de "résistance à la progression des fissures de fatigue" – la capacité de résister à la progression lente d'une fissure préexistante au moyen de cycles de tension et de relaxation. Les produits présentent également de bonnes caractéristiques d'endurance et de tenue à la corrosion. Les avantages de cette invention sont notamment la prolongation de la vie de l'avion et une plus grande sécurité. Par ailleurs, en réduisant ou éliminant le recours aux soi-disant "bouches-fissures" – des bandes de métal fixées à l'intérieur de la tôle de

fuselage pour retarder la progression des fissures – la meilleure tolérance aux dommages des produits permet la construction d'appareils qui consomment moins de combustible.

23. En janvier 1993, l'Association de l'Aluminium, dont le siège est à Washington, D.C., accède à la demande d'Alcoa en lui accordant la désignation internationale d'alliage "2524". Cette désignation numérique qui indique les limites des teneurs admises dans la composition des alliages conformément aux règles de l'Association, est le nom par lequel Alcoa désigne certains produits couverts par le brevet '639.

24. L'alliage 2524 allait être très demandé par les fabricants d'avions, notamment les deux fabricants les plus importants, Boeing Co ("Boeing") et le consortium européen Airbus ("Airbus"). Boeing utilise notamment le 2524 pour la tôle de fuselage sur ses appareils de la série 777 alors qu'Airbus l'utilise sur ses appareils A340-500 et A340-600. Cet alliage est également utilisé pour les appareils fabriqués par la société canadienne Bombardier, Inc. ("Bombardier") et la société brésilienne Embraer, S.A. ("Embraer").

25. Pechiney, n'ayant pas d'alliage comparable et se rendant compte que cette carence la plaçait dans une position gravement désavantageuse sur le plan de la concurrence, chercha alors à répliquer l'invention d'Alcoa. Le premier résultat de ces travaux fut un alliage élaboré au centre de recherche de Pechiney à Voreppe (France) et fabriqué à l'usine de Pechiney à Issoire (France) auquel l'Association de l'aluminium accorda la désignation "2024A."

26. En 1997, Pechiney commença à commercialiser le 2024A auprès des fabricants d'avions.

27. Consciente du fait que le 2024A n'était en fait pas beaucoup plus qu'une copie du 2524, Pechiney – par le truchement de Pechiney Rhenalu – introduit une requête de jugement déclaratoire devant ce Tribunal en mai 1999. Cette action en justice prétendait obtenir une déclaration annulant le brevet '639 et selon laquelle le 2024A n'enfreignait pas ce brevet.



28. A l'issue d'un procès de dix jours en janvier 2001, un jury, puis le Tribunal (dans son avis en date de septembre 2002), rejeta toutes les demandes de Pechiney. Cf. Pechiney Rhenalu v. Alcoa, Inc., 224 F. Supp. 2d 773 (D. Del. 2002). Dans un avis de 34 pages, le président du Tribunal, Chief Judge Robinson, déclara qu'"Alcoa avait démontré avec une prépondérance de preuves que le 2024A enfreignait les revendications affirmées du brevet '639," et conclut à la validité et la mise en vigueur du brevet '639. Id. à 799, 906.

29. Pechiney ne fit pas appel du jugement, lequel est frappé de préclusion et qui a l'autorité de la chose jugée.

#### Deuxième tentative de Pechiney de répliquer l'alliage 2524

30. Alors que Pechiney prétendait avoir accepté le jugement du Tribunal du District, elle continuait secrètement à chercher un moyen alternatif lui permettant de répliquer l'alliage 2524 d'Alcoa, en violation délibérée du brevet '639.

31. Vers le 18 février, 2003, le second substitut d'alliage de Pechiney reçut la désignation "2056" de l'Association de l'Aluminium. Dans le cadre de la demande de cette désignation, Pechiney déclara à l'Association de l'Aluminium qu'elle avait mis l'alliage en vente et qu'elle l'avait fourni "en quantités commerciales" les douze mois qui précédents.

32. L'alliage 2056 n'est qu'une autre copie du 2524. L'alliage fut élaboré au même centre de Voreppe, en France, où le 2024A avait été élaboré antérieurement par Pechiney, et fabriqué à la même usine d'Issoire, en France, où Pechiney avait fabriqué antérieurement l'alliage de contrefaçon. A l'instar du 2024A, le 2056 contient tous les éléments essentiels du 2524. La composition de l'alliage 2056 se situe dans le cadre des revendications révélées dans le brevet '639 d'Alcoa. Les propriétés de l'alliage font également partie des revendications révélées dans le brevet '639.

33. Le 7 juillet 2003, Pechiney tenta d'obtenir un brevet américain pour le 2056 en déposant une demande auprès du Bureau américain des Brevets et des Marques de Commerce au nom

RLF1-3025217-1

de ses salariés, Timothy Warner, Ronan Dif, Bernard Bes et Hervé Ribes. Ces individus étaient préalablement engagés dans la conception, les essais et la fabrication du 2024A. Chacun d'entre eux a fourni une déposition sous serment dans le cadre de la procédure pour contrefaçon engagée contre Alcoa et les témoignages de MM. Warner, Bes et Ribes furent présentés au cours du procès.

34. La demande de brevet, intitulée "Membre structurel d'avion fabriqué à partir d'un alliage Al-Cu-Mg," décrit l'invention prétendue comme étant "un alliage AlCuMg possédant une meilleure tolérance aux dommages, une résistance mécanique au moins équivalente, et une plus grande résistance à la corrosion en comparaison avec l'antériorité," et pouvant être utilisée "comme tôle de fuselage pour avion." La demande est actuellement en instance.

35. Le même mois, Alcan annonça son offre publique d'achat pour l'acquisition de Pechiney. A l'issue de l'approbation du conseil de Pechiney, Alcan pris le contrôle de Pechiney en décembre 2003. En février 2004, Alcan acquit le reste des actions de Pechiney qu'elle ne possédait pas encore et Pechiney devint une filiale d'Alcan détenue à 100%.

#### Préparations d'Alcan pour la mise en vente imminente du 2056 aux États-Unis

36. Depuis l'acquisition, et nonobstant le fait qu'Alcan sait que le 2056 enfreint le brevet '659 d'Alcoa, Alcan s'est lancé dans la commercialisation active du 2056 en concurrence directe avec l'alliage 2524 d'Alcoa, sur l'internet, au cours de conférences industrielles et d'entretiens particuliers.

37. Vers le mois d'avril 2004, les agents d'Alcan eurent des entretiens avec des représentants du Premier Institut de Conception Aéronautique de Chine [First Aircraft Institute ("FAI")], qui développe des avions commerciaux de grande envergure. Les agents d'Alcan proposèrent à la FAI de remplacer le 2524 par le 2056 dans le cadre du programme régional de pointe chinois pour la fabrication d'avions [Advanced Regional Jet program].

38. Au même moment, les agents d'Alcan rencontraient les représentants de DaimlerChrysler Aerospace Airbus GmbH, le membre allemand du consortium Airbus, et les représentants d'Embraer, pour leur proposer le 2056 pour être utilisé dans les avions dont la conception est en cours au sein de ces compagnies.

RLF1-3025217-1

39. Le 8 juin 2004, Warner et Bes, les agents d'Alcan, firent une présentation à l'occasion de la conférence AeroMat 2004 à Seattle dont le sujet était "Le développement de tôles de fuselage de grande résistance," dans laquelle il comparaient explicitement le 2056 au 2524. Lors d'une autre présentation à la même conférence, celle-ci intitulée "Solutions métalliques avancées pour tôles de fuselage," Warner, Bes et Ribes, ainsi que l'agent d'Alcan Sjoerd van der Veen, caractérisèrent le 2056 comme étant une "offre d'Alcan" qui était "[d]isponible au niveau industriel," et pour lequel "[u]n ensemble de données complètes étaient disponibles."

40. Le 18 novembre 2004, le conseil des brevets externe d'Alcoa envoya un courrier à William H. Jarriels, Vice président et conseil général d'Alcan Corp., au 6060 Parkland Boulevard, Mayfield Heights, OH 44124. La lettre avait en référence l'alliage 2056 et le brevet '639 d'Alcoa – c'est-à-dire exactement le même brevet qui, auparavant, avait fait l'objet d'une action en justice contre Pechiney, le prédécesseur d'Alcan.

41. Par ce courrier, le conseil d'Alcoa demandait à M. Jarriels de "[b]ien vouloir lui communiquer ses intentions en ce qui concerne l'alliage en référence ci-dessus."

42. Le 20 janvier 2005, le conseil d'Alcoa reçut une réponse par écrit d'Eileen Burns Lerum, Vice présidente et conseil principal du contentieux auprès de Pechiney Plastic Packaging, Inc. Madame Lerum faisait partie du service juridique de Pechiney au cours du procès à l'encontre d'Alcoa concernant le brevet '639.

43. Le courrier de Madame Lerum avait pour en-tête le nom d'Alcan et le logo de la société. Son adresse postale – 8770 West Bryn Mawr Avenue, Chicago, IL 60651 – était celle du siège d'Alcan Corp. de Delaware.

44. Madame Lerum signalait que "M. Jarriels ne faisant plus partie de l'organisation d'Alcan" et que ce serait elle qui "reverrait cette question" à sa place.

45. Le 17 mars 2005, Madame Lerum informa le conseil d'Alcoa par écrit du fait qu'"Alcan avait l'intention d'offrir" les produits 2056 pour la vente.

46. Récemment, Alcan a commencé à mettre en vedette sur le site web de la société ses "nouveaux alliages/nouvelles solutions . . . pour des panneaux de fuselage à haute tolérance aux dommages." Une brochure disponible sous la rubrique du site web dénommée "Offre Globale" décrit actuellement le 2056 comme étant "particulièrement recommandé en application pour le fuselage," et signale que l'alliage peut être "livré en trempe O ou T3 selon les besoins du client." La brochure indique, sous la rubrique "Disponibilités," que "les tôles plaquées 2056 pour fuselage sont disponibles dans une gamme d'épaisseurs allant de 1.6 mm jusqu'à 8 mm." Une autre brochure sur le site web d'Alcan commente: "Alcan, à son usine d'Issoire, fabrique une gamme complète d'alliages et de qualités de trempe pour applications spécifiques. Les alliages classiques – conformes aux spécifications AMS-QQA ou EN – en plus des alliages pour tôles récemment développés – par exemple les 2056, 6056, 6156 et 2024-HF – sont disponibles."

47. Airbus et Embraer ont récemment réalisé des essais sur le 2056 et sont prêts à le qualifier comme remplacement du 2524, s'ils ne l'ont pas déjà fait. Les deux sociétés bénéficient de chiffres d'affaires importants provenant de leurs ventes d'avions aux États-Unis.

48. Le 12 juin 2006, les avocats d'Alcoa envoyèrent un courrier à David L. McAusland, Vice président et principal directeur juridique d'Alcan, Inc., par lequel ils lui communiquaient les conclusions d'Alcoa, selon lesquelles les activités d'Alcan risquaient de façon imminente d'enfreindre le brevet '630, et lui faisait part des intentions d'Alcoa dans le but de protéger ses droits au titre du brevet.

49. Au regard de ce qui précède, y compris l'enfreinte antérieure de Péchiney au brevet '639 d'Alcoa, il y a entre Alcoa et Alcan un différend grave et continu relevant de la compétence des tribunaux en ce qui concerne le projet imminent d'Alcan de mettre en vente aux États-Unis, ou à des fabricants étrangers susceptibles d'importer des produits contenant l'alliage aux États-Unis,

dont il s'agit de savoir si celui-ci enfreint le brevet '639. Les activités d'Alcan ont suscité chez Alcoa la crainte justifiée de se voir subir un préjudice et une perte imminentes du fait de la contrefaçon d'Alcan menaçant le brevet '639. Une telle enfreinte provoquerait un préjudice grave et irréparable à Alcoa.

PREMIER MOTIF

(Contrefaçon)

50. Alcoa réitère et réaffirme chacune des déclarations faites par elle aux paragraphes 1 à 49 inclus.

51. Les Défendeurs ont engagé des préparations significatives et ont pris des mesures concrètes dans le but de mettre en vente aux États-Unis des produits d'alliage d'aluminium, y compris notamment les produits 2056 d'Alcan, qui enfreignent au brevet américain d'Alcoa [United States Patent] No. 5.213.639, que ce soit littéralement ou au titre de la théorie des équivalents, en violation de la loi 35 U.S.C. § 271(a).

DEUXIÈME MOTIF

(Incitation délibérée)

52. Alcoa réitère et réaffirme chacune des déclarations faites par elle aux paragraphes 1 à 51 inclus.

53. Les Défendeurs ont engagé des préparations significatives et ont pris des mesures concrètes dans le but de proposer à des fabricants d'avions étrangers la vente de produits d'alliage d'aluminium, y compris notamment les produits 2056 d'Alcan, qui enfreignent au brevet américain d'Alcoa [United States Patent] No. 5.213.639, que ce soit littéralement ou au titre de la théorie des équivalents, en violation de la loi 35 U.S.C. § 271(b).

Demande de faire droit

CONCLUSION. Alcoa sollicite un jugement:

(a) déclarant que la fabrication, l'utilisation, les offres de vente, ou la vente de l'alliage 2056 aux États-Unis, ou l'importation de produits contenant l'alliage 2056 aux États-Unis constitue enfreinte au brevet '639;

(b) déclarant que les actions des Défendeurs ont été délibérées;

(c) accordant à Alcoa une injonction permanente visant à interdire aux Défendeurs, leurs agents, employés, salariés, successeurs, contractants, l'offre ou la vente de l'alliage 2056 aux États-Unis ou à des fabricants étrangers dont on peut raisonnablement présumer qu'ils offriront les produits fabriqués à partir de cet alliage aux États-Unis;

(d) accordant à Alcoa les dépens de cette action en justice ainsi que des honoraires d'avocat raisonnables; et

(e) accordant à Alcoa tout autre réparation que le Tribunal considérera juste et appropriée.

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*Conseils du Demandeur Alcoa, Inc.*



# EXHIBIT A



US005213639A

United States Patent [19]  
Colvin et al.

[11] Patent Number: 5,213,639  
[45] Date of Patent: May 25, 1993

- [54] DAMAGE TOLERANT ALUMINUM ALLOY PRODUCTS USEFUL FOR AIRCRAFT APPLICATIONS SUCH AS SKIN
- [75] Inventors: Edward L. Colvin, O'Hara Township, Allegheny County; Jocelyn L. Pettit, New Kensington, both of Pa.; Robert W. Westerlund, Bettendorf, Iowa; Paul E. Megausen, Plum Boro, Pa.
- [73] Assignee: Aluminum Company of America, Pittsburgh, Pa.
- [21] Appl. No.: 847,352
- [22] Filed: Mar. 6, 1992

## Related U.S. Application Data

- [63] Continuation-in-part of Ser. No. 572,625, Aug. 27, 1990, abandoned, Continuation-in-part of Ser. No. 572,626, Aug. 27, 1990, abandoned.
- [51] Int. Cl.<sup>5</sup> ..... C22F 1/04
- [52] U.S. Cl. .... 148/693; 148/552; 148/700; 148/417; 148/439; 428/654
- [58] Field of Search ..... 148/552, 693; 700, 417, 148/439; 428/654; 420/533

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"Aluminum Alloy Development for Subsonic and Supersonic Aircraft", M. V. Hyatt, et al., *Science and Engineering of Light Metals*, published by The Japan Institute of Light Metals, Tokyo, Oct. 1991, pp. 273 to 280.

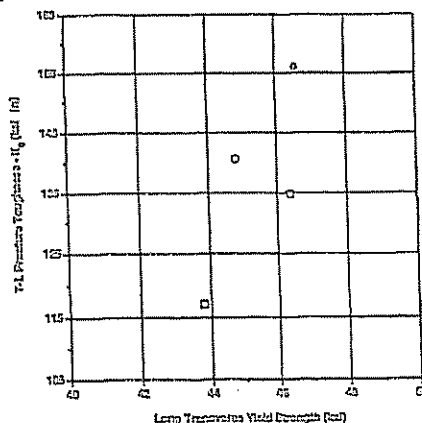
Primary Examiner—R. Dean

Assistant Examiner—Robert R. Koehler

Attorney, Agent, or Firm—Carl R. Lippert

## [57] ABSTRACT

A method of producing a sheet product and improved products having improved levels of toughness and fatigue crack growth resistance at good strength levels. The method comprises providing an aluminum base alloy containing 4 to 4.5% Cu, 1.2 to 1.5% Mg, 0.4 to 0.6% Mn, 0.12% max. Fe, 0.1% max. Si, the remainder aluminum, incidental elements and impurities and hot rolling the alloy, heating the alloy to above 910° F. and additionally hot rolling it in a range of about 600° to 900° F., solution heat treating, preferably for a time of less than about 15 minutes at a solution heat treating temperature, and rapidly cooling and naturally aging. The invention products have very good combinations of strength together with high fracture toughness or low fatigue crack growth rate, or both, making them well suited for aerospace applications such as fuselage skin. The products preferably include a corrosion protecting cladding of aluminum or aluminum alloy.



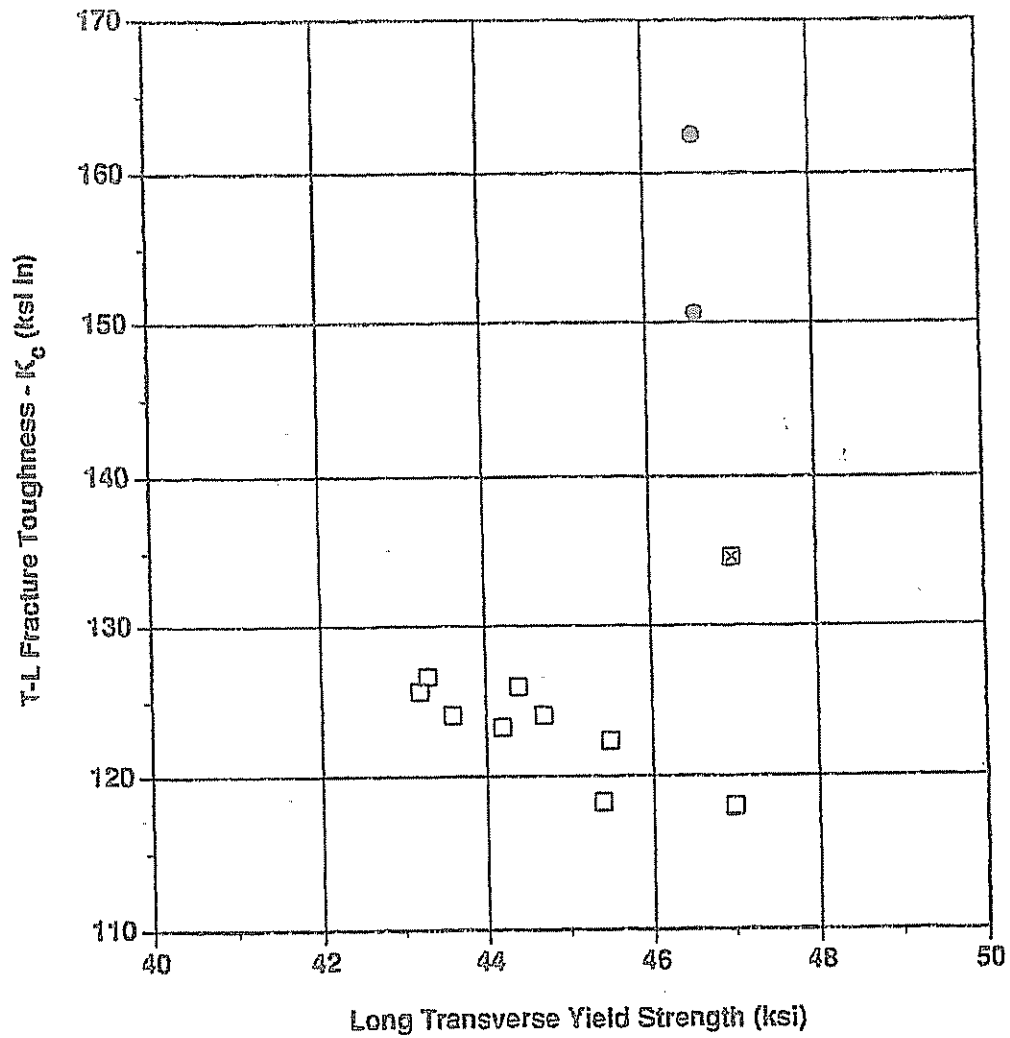
- Invention  
□ Invention Compared/Sub. Held at Low Temperature Before Hot Rolling  
□ 2024-T3 Compared/Invention Processing  
□ 2024-T3 Compared/Conventional Processing

U.S. Patent

May 25, 1993

Sheet 1 of 12

5,213,639



- Invention
- ⊠ 2024 Composition/Invention Processing
- 2024-T3

Figure 1

U.S. Patent

May 25, 1993

Sheet 2 of 12

5,213,639

Fatigue Crack Propagation Rate vs. Crack Length  
for Invention and Special Process 2024-T3  
 $\Delta K=22 \text{ ksi}\sqrt{\text{in.}}$ ,  $R=0.33$ , T-L Orientation

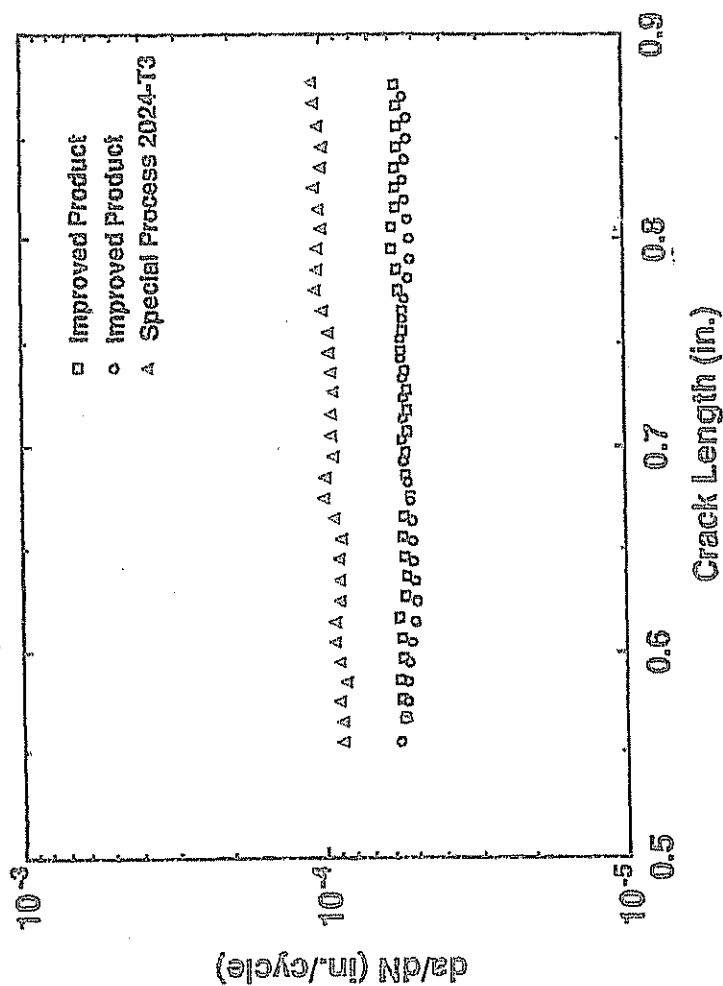


Figure 2

U.S. Patent

May 25, 1993

Sheet 3 of 12

5,213,639

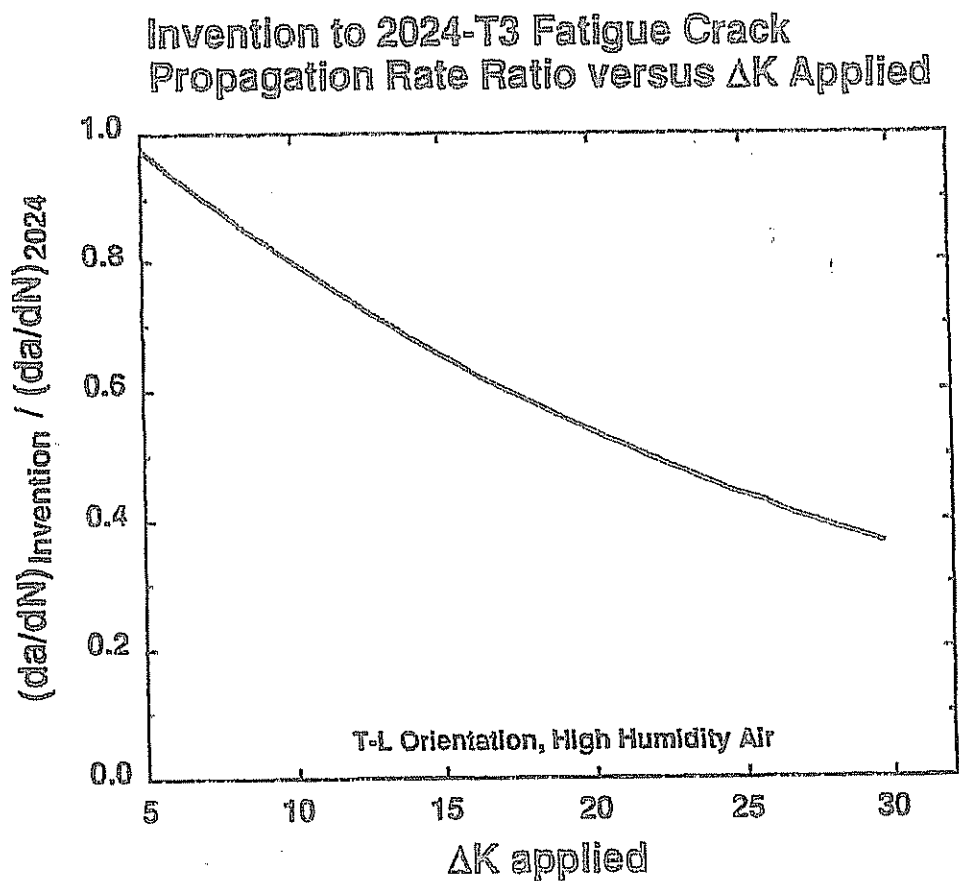


Figure 2a

U.S. Patent

May 25, 1993

Sheet 4 of 12

5,213,639

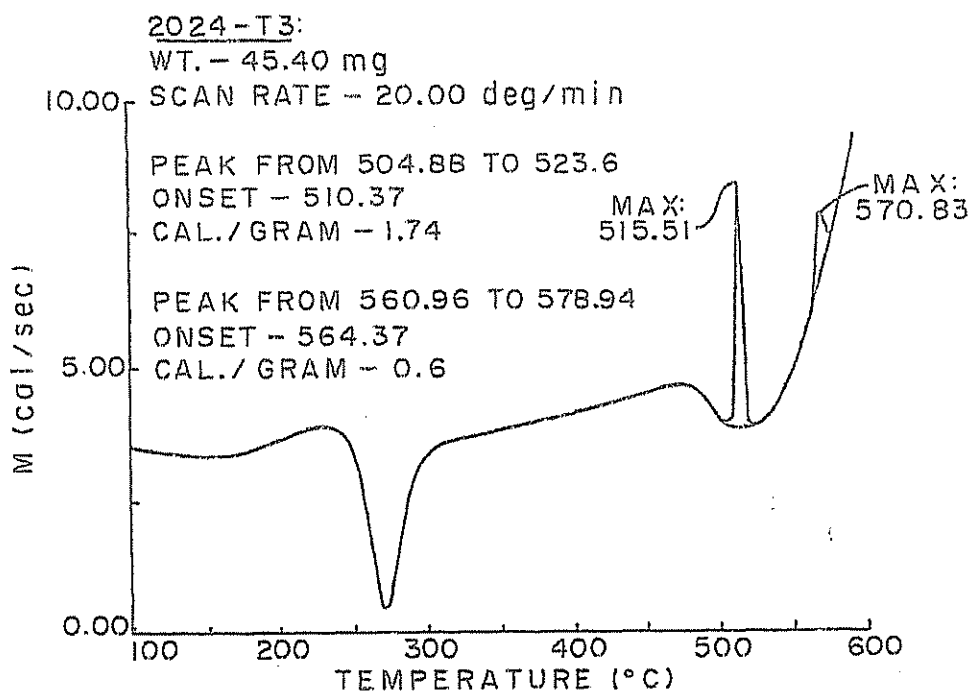


FIG. 3

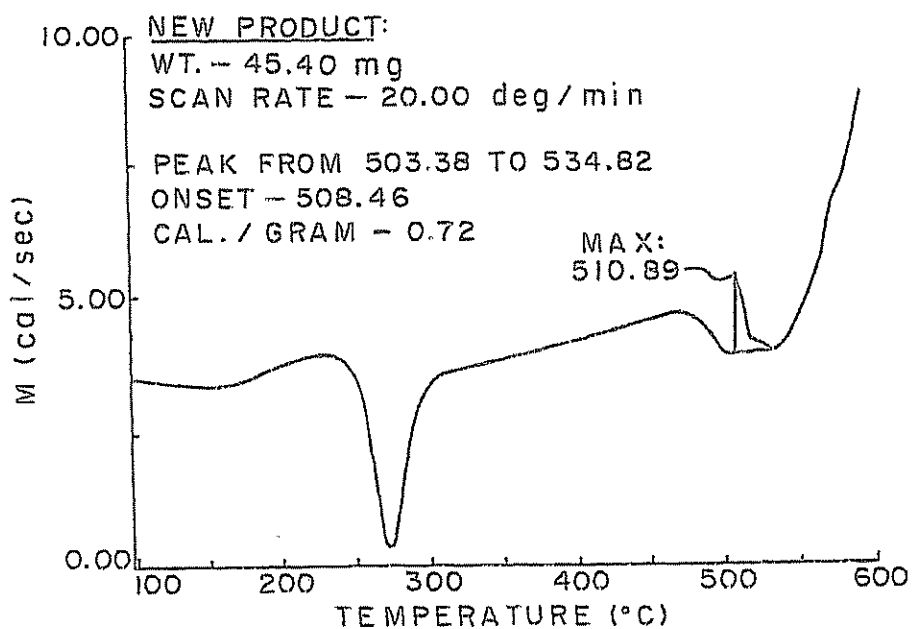


FIG. 4

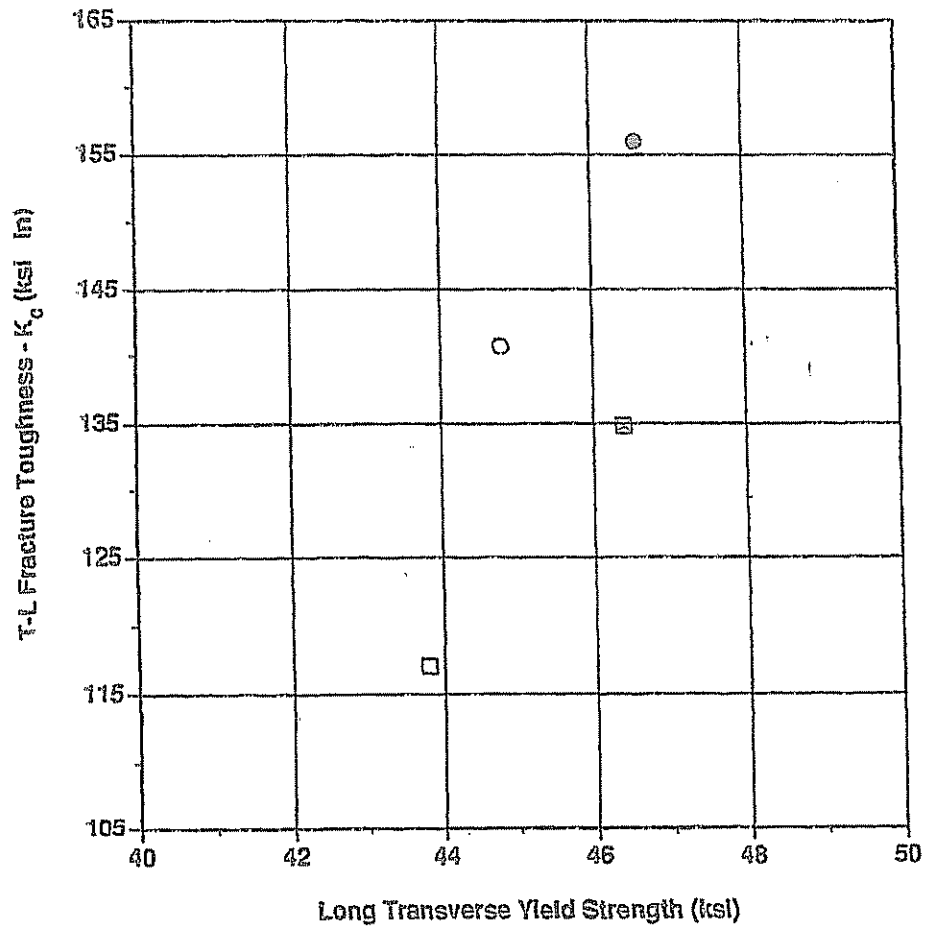


U.S. Patent

May 25, 1993

Sheet 5 of 12

5,213,639



- Invention
- Invention Composition/Slab Held at Low Temperature Before Hot Rolling
- 2024-T3 Composition/Invention Processing
- 2024-T3 Composition/Conventional Processing

Figure 5

U.S. Patent

May 25, 1993

Sheet 6 of 12

5,213,639

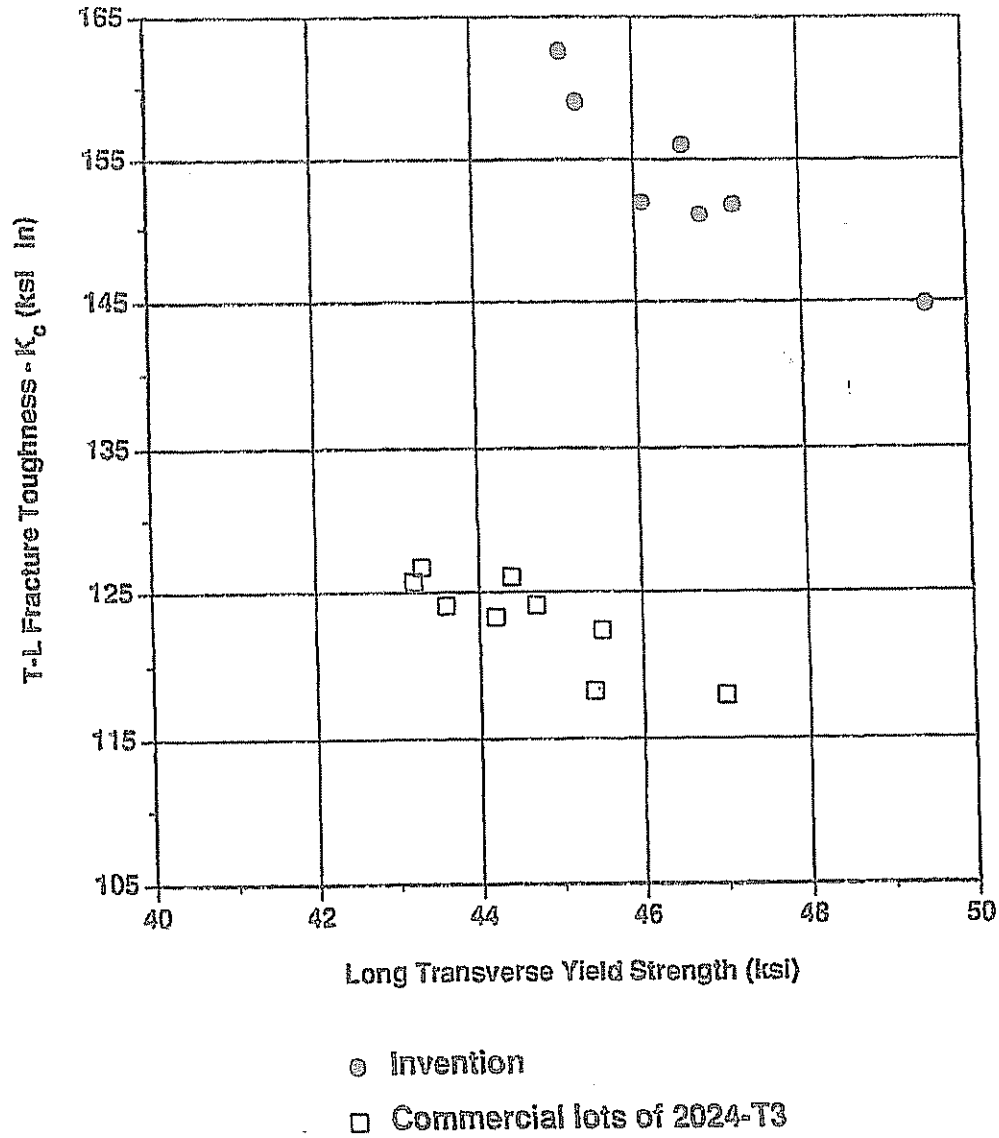


Figure 6

U.S. Patent

May 25, 1993

Sheet 7 of 12

5,213,639

Fatigue Crack Propagation Rate versus Change in  
Crack Length,  $\Delta K=30$  ksi $\sqrt{\text{in.}}$ ,  $R=0.1$ , High Humidity Air

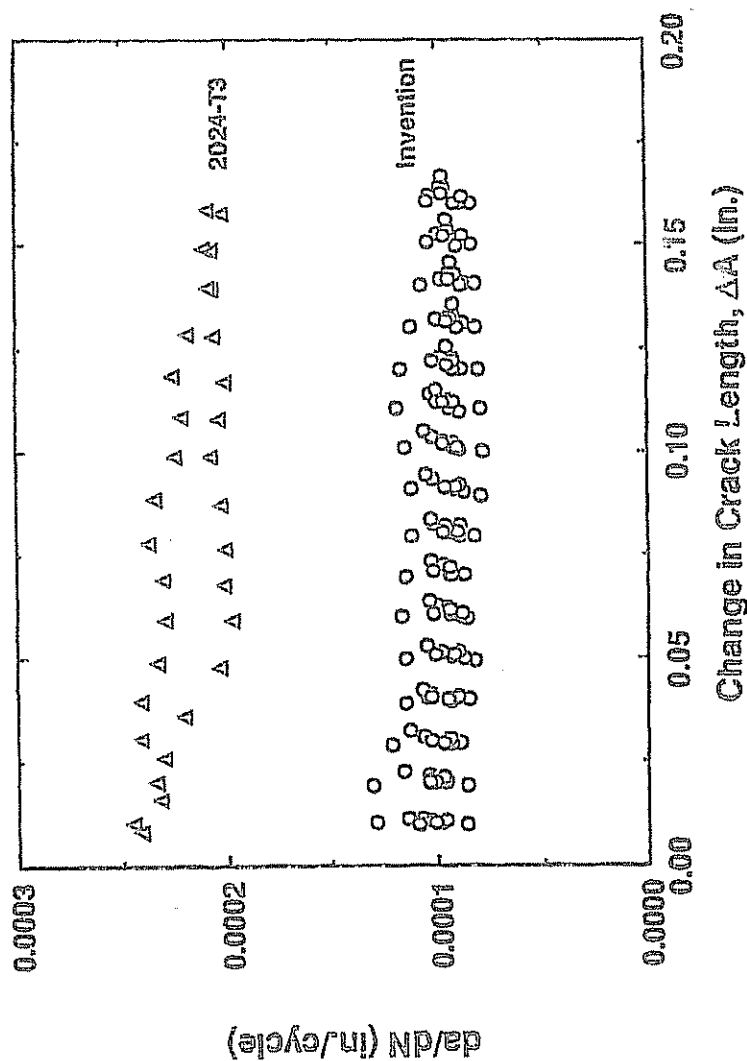


Figure 7

U.S. Patent

May 25, 1993

Sheet 8 of 12

5,213,639

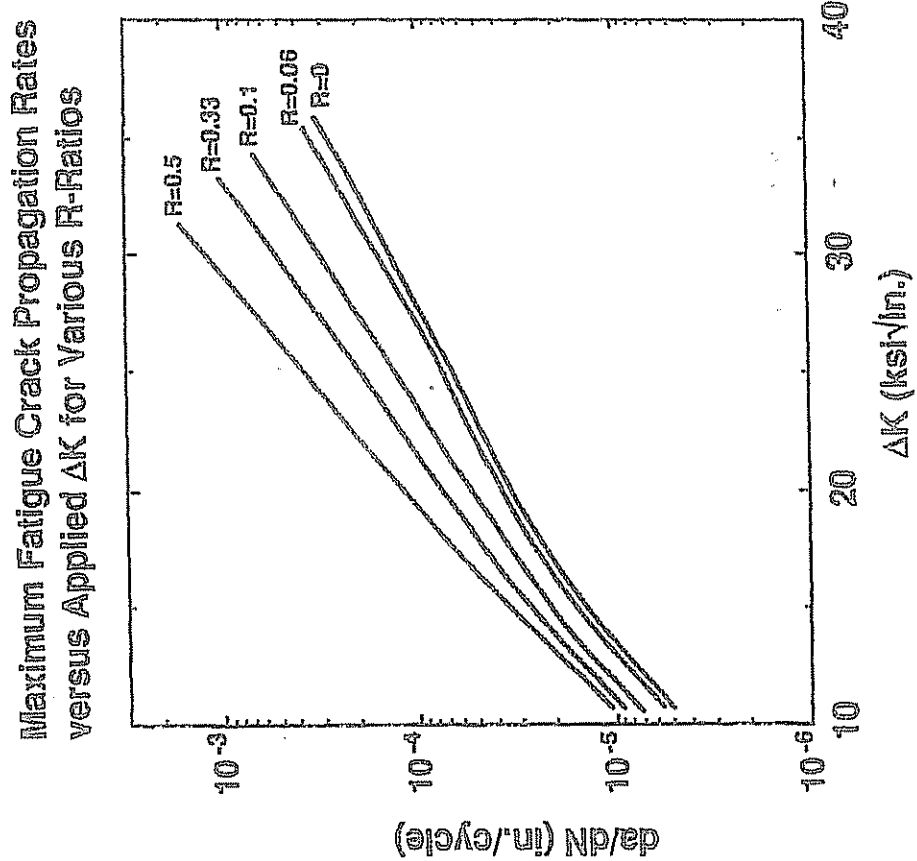


Figure 8

U.S. Patent

May 25, 1993

Sheet 9 of 12

5,213,639

Maximum Fatigue Crack Propagation Rates  
versus Applied  $\Delta K$  for  $R = 0.33$

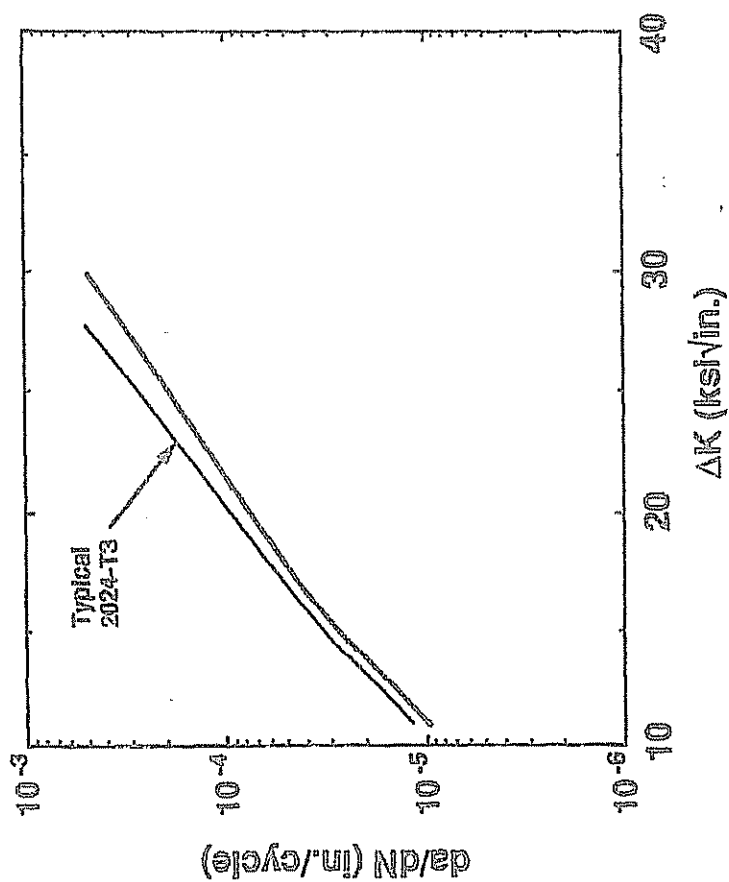


Figure 8a

U.S. Patent

May 25, 1993

Sheet 10 of 12

5,213,639

Maximum Fatigue Crack Propagation Rates  
versus Applied  $\Delta K$  for  $R = 0.1$

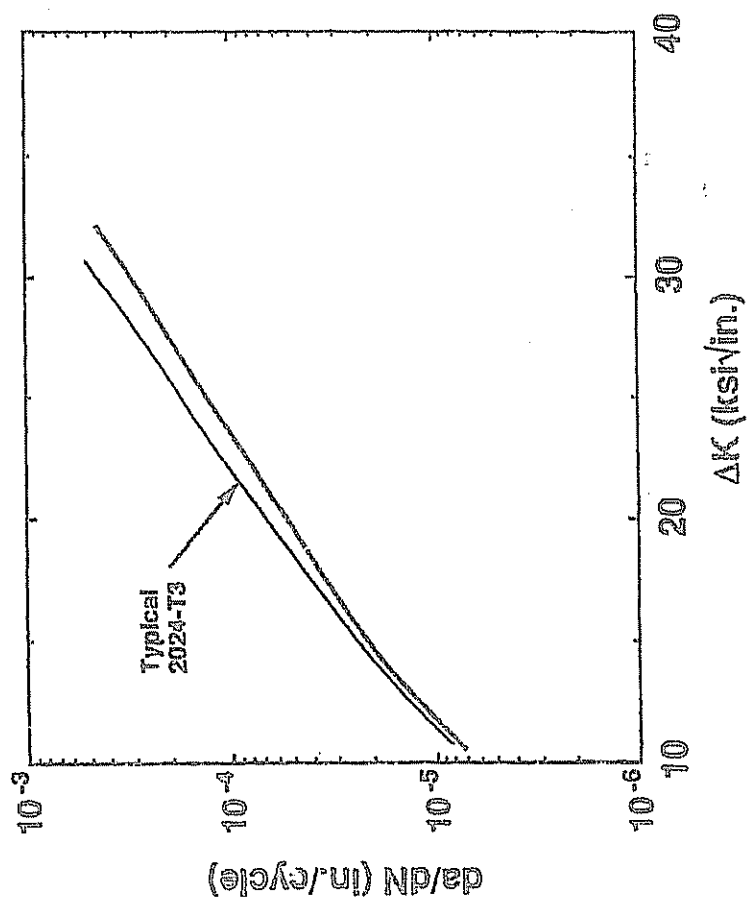


Figure 8b



U.S. Patent

May 25, 1993

Sheet 11 of 12

5,213,639

Maximum Fatigue crack Propagation Rates versus  
Applied  $\Delta K$  for Various R-Ratios, Constant  $\Delta K$  Test

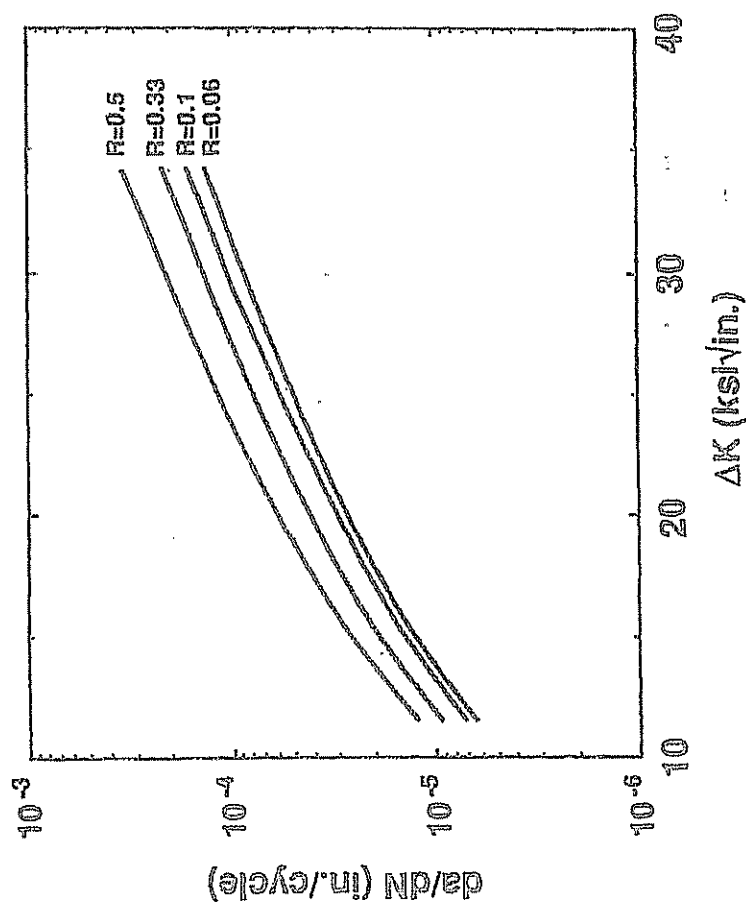


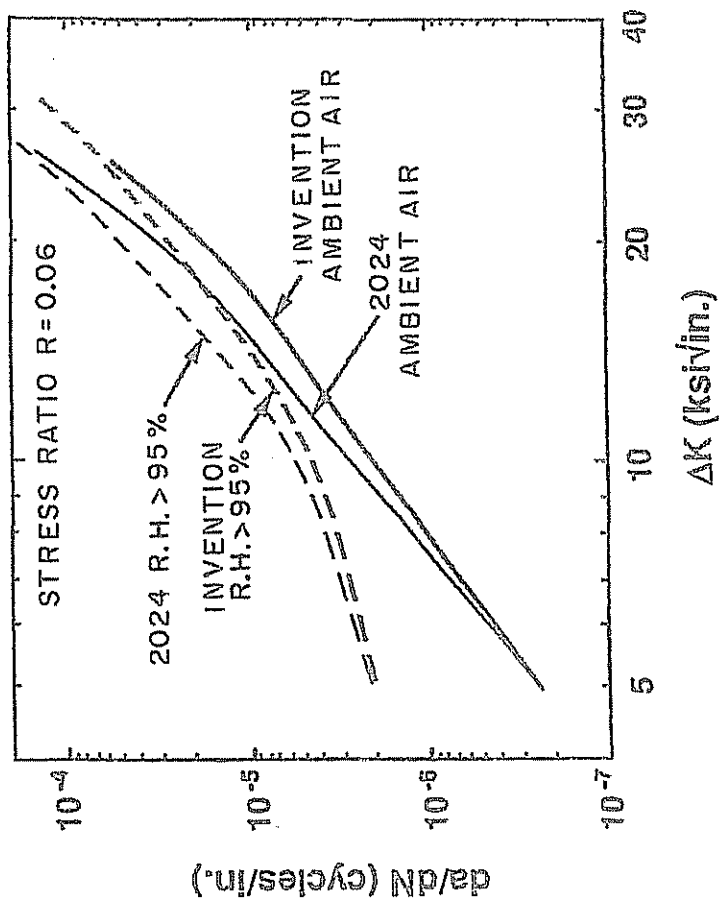
Figure 9

U.S. Patent

May 25, 1993

Sheet 12 of 12

5,213,639



Effect of Humidity on Fatigue Crack Growth Rates of Invention and 2024-T3 Sheet

Figure 10

1

5,213,639

2

# DAMAGE TOLERANT ALUMINUM ALLOY PRODUCTS USEFUL FOR AIRCRAFT APPLICATIONS SUCH AS SKIN

## BACKGROUND OF THE INVENTION

This application is a continuation-in-part of U.S. patent application Ser. Nos. 07/572,625 and 07/572,626, both of which were filed Aug. 27, 1990, the entire contents of which are incorporated herein by reference, and both patent applications now abandoned.

This invention relates to aluminum alloys suitable for use in aircraft applications and, more particularly, it relates to an improved aluminum alloy and processing thereof having improved resistance to fatigue crack growth and fracture toughness and suited to use as aircraft skin.

The design of commercial aircraft requires different sets of properties for different types of structures on the airplane. In many parts, resistance to crack propagation either in the form of fracture toughness or fatigue crack growth is essential. Therefore, many significant benefits can be realized by improving fracture toughness and resistance to fatigue crack propagation.

A new material with improved toughness, for example, will have a higher level of damage tolerance. On the aircraft, this translates to improved safety for passengers and crew and weight savings in the structure which allows for improved fuel economy, longer flight range, greater payload capacity or a combination of these.

Cyclic loading occurs on a commercial jet airplane with each flight as the interior of the airplane is pressurized and then depressurized. Typically, airplanes may see up to 100,000 such pressurization cycles during their normal service lifetime. Slower rates of crack growth during cyclic loading would allow for weight savings, longer service lives (more pressurizing cycles), decreased inspection frequencies and even greater passenger safety. Thus, it will be noted that great benefit is derived from improved fracture toughness and resistance to fatigue crack growth, both of which are related to cyclic loading.

U.S. Pat. No. 4,336,075 discloses the use of AA2000 type aluminum alloy for aircraft wings.

The present invention provides aluminum base alloy sheet products and a method of fabricating sheet products from a body of the alloy. Further, the invention provides aluminum alloy sheet products suitable for aircraft applications such as aircraft fuselage panels, which sheets are clad with a corrosion protecting outer layer. It can be envisioned that the invention can also have benefits in other areas of the aircraft where fracture toughness or fatigue crack growth resistance (or both) are important, such as lower wing skins, horizontal stabilizer, pressure bulkheads and fuselage reinforcements.

## SUMMARY OF THE INVENTION

A principal object of the invention is to provide an aluminum alloy and sheet product formed therefrom, the sheet product having improved fracture toughness and resistance to fatigue crack growth while maintaining high strength properties and corrosion resistance.

A further object of the present invention is to provide aluminum alloy sheet products having improved frac-

ture toughness and resistance to fatigue crack growth for aircraft panels.

Yet a further object of the present invention is to provide aluminum alloy sheet products and a process for producing the sheet products so as to provide improved fracture toughness and increased resistance to fatigue crack growth while still maintaining high levels of strength.

Still a further object of the invention is to provide a method for processing an aluminum alloy into clad sheet products having improved resistance to fatigue crack growth while maintaining high strength properties and corrosion resistance.

And still a further object is to provide an Al-Cu-Mg-Mn clad sheet product for use as aircraft panels such as wing or fuselage skins having improved resistance to fatigue crack growth while maintaining high strength levels and improved fracture toughness.

These and other objects will become apparent from a reading of the specification and claims and an inspection of the claims appended hereto.

In accordance with these objects, there is provided a method of producing a sheet product having improved levels of toughness and fatigue crack growth resistance while maintaining high strength, the method comprising providing a body of an aluminum base alloy preferably containing about 4.15 to 4.5% Cu, 1.2 to 1.45% Mg, 0.4 to 0.7% Mn, 0.1% max. Fe, 0.1% max. Si, the remainder substantially aluminum, incidental elements and impurities. The method further comprises heating a body of the alloy to above 900° F. to dissolve soluble constituents. Thereafter, the body is hot rolled in the range of about 600° to 900° F., and possibly cold rolled, and solution heat treated for a time of less than about 60 minutes, for example, at the solution heat treating temperature, then rapidly cooled (and, optionally, plastically deformed) and naturally aged to provide a sheet product with improved levels of fatigue crack growth resistance and fracture toughness while maintaining high strength levels.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows fracture toughness  $K_{IC}$  and yield strength data for improved material and for 2024.

FIG. 2 is a graph showing fatigue crack growth rate data versus crack length for specially processed 2024 in the solution heat treated, cold worked and naturally aged T3 temper and for the improved product in accordance with the invention.

FIG. 2a is a plot of the ratio of the fatigue crack growth rate for the improvement divided by that for 2024 versus  $\Delta K$ .

FIG. 3 is a differential scanning calorimetry curve of 2024-T3.

FIG. 4 is a differential scanning calorimetry curve of an aluminum alloy product in accordance with the invention.

FIG. 5 shows fracture toughness and yield strength data for different sheet materials from Example 2 hereof.

FIG. 6 shows fracture toughness and yield strength data for sheet products of the invention and for 2024-T3.

FIG. 7 shows fatigue crack propagation rate versus change in crack length for the invention product and for 2024-T3.

FIGS. 8, 8a and 8b are plots of maximum fatigue crack growth rate versus  $\Delta K$  for the constant load test.

5,213,639

FIG. 9 plots maximum fatigue crack growth rate versus  $\Delta K$  for the constant  $\Delta K$  test.

FIG. 10 plots fatigue crack growth rate versus  $\Delta K$  for different relative humidity levels (95% humidity and ordinary ambient).

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Typically, the alloy of the present invention preferably comprises about 3.8 or 3.9 or 4 to 4.5% Cu, 1.2 or 1.3 to 1.5 or 1.6% Mg, 0.4 to 0.8% Mn, 0.01 or 0.02 to 0.1 or 0.15% Fe, 0.01 or 0.02 to 0.1 or 0.15% Si, the balance aluminum, incidental elements and impurities. Unless indicated otherwise, all percentages for alloy elements herein are weight percent.

A preferred alloy would contain about 4.1 to 4.4% Cu, about 1.2 to 1.45% Mg, about 0.4 to 0.7% Mn, Fe not exceeding about 0.1 or 0.15%, for instance about 0.01 or 0.02 to 0.12 or 0.15% Fe, Si not exceeding about 0.1 or 0.15% maximum, for instance about 0.01, or 0.02 to 0.1 or 0.12% Si, the balance essentially aluminum, incidental elements and impurities. Impurity element Zn preferably has a maximum of 0.2 or 0.25% and Cr a maximum of 0.1 or possibly 0.2%. Zr could be added up to 0.5% Zr, with a range for Zr being 0.05 to 0.15 or 0.2 or 0.25%, such as if it is desired to make an unrecrystallized product such as a product wherein no more than 20 or 25 vol. % of the product is recrystallized. At levels of Zr above about 0.12%, coarse primary Zr-bearing particles might be formed in casting and these can be detrimental to toughness, unless care is taken to avoid such. Impurities are preferably limited to 0.05% each and the combination of impurities preferably should not exceed 0.15%. The sum total of incidental elements and impurities preferably does not exceed 0.25%, although in some cases incidental elements such as V, Hf, Cr, Ag or Sc can be included in amounts of up to about 0.5 or 1%, for instance 0.05 to 0.1 or 0.2%. A typical alloy composition would contain about 4.25% Cu, 1.35% Mg, 0.5% Mn, 0.12% max. Fe and 0.1% max. Si with Fe plus Si not totaling more than 0.20 and preferably not more than 0.15.

Mn contributes to or aids in grain size control during operations that can cause the metal to recrystallize. Very large grains are detrimental to properties such as fracture toughness, formability and corrosion resistance.

Fe and Si are normally considered impurities in aluminum and in practicing the invention their levels are preferably kept relatively low to limit formation of the constituent phases  $Al_7Cu_2Fe$  and  $Mg_2Si$  which are detrimental to fracture toughness and fatigue crack growth resistance. These phases have low solid solubility in Al-alloy and once formed cannot be eliminated by thermal treatments. Formation of  $Al_7Cu_2Fe$  and  $Mg_2Si$  phases can also lower the strength of the product because their formation reduces the amount of Cu and Mg available to form strengthening precipitates. A decrease in Fe and Si increases toughness and resistance to fatigue crack growth. Thus, in the present invention, it is preferred to control Fe to below 0.1 or 0.15% and Si to below 0.1 or 0.15%, at least where large direct chill (DC) casting is used to make the alloy ingot. Spray casting or other ingot producing techniques may make higher amounts of Fe and Si more tolerable such as 0.2% or 0.3% or 0.4% Fe or Si, or even 0.5% of each.

Preferably, Cu and Mg are carefully controlled to maintain good strength while providing the benefits in

toughness and fatigue. The Cu and Mg levels should be low enough to allow for dissolution of the slightly soluble  $Al_2CuMg$  and  $Al_2Cu$  constituent phases during high temperature processing yet high enough to increase or maximize the amount of free Cu and Mg available to adequately strengthen the alloy.

The following equations may be used to estimate the "free Cu" and "free Mg"; that is, the amount of Cu and Mg that are available to form strengthening phases.

$$Cu_{Free} = Cu_{Total} - 2.25Fe - 0.74(Mn - 0.2)$$

$$Mg_{Free} = Mg_{Total} - 1.73(Si - 0.05)$$

As well as providing the alloy product with controlled amounts of alloying elements as described herein, it is preferred that the alloy be prepared according to specific method steps in order to provide the most desirable characteristics of both strength, fracture toughness, corrosion resistance and resistance to fatigue crack growth as required, for example, for use as aircraft skins or panels. The alloy as described herein can be provided as an ingot or slab for fabrication into a suitable wrought product by casting techniques currently employed in the art for cast products with continuous casting being preferred. Slab's resulting from belt casters or roll casters also may be used. Alternately, the alloy can be spray cast into the ingot or slab wherein liquid metal drops are solidified against solidified ingot or stock.

In a broader aspect of the invention, the alloy consists essentially of about 3.8 to 4.5% Cu, 1.2 to 1.85% Mg, 0.3 to 0.78 or 0.8 or 0.9% Mn, 0.5 wt. % max. Fe, 0.5% Si, the balance aluminum, incidental elements and impurities.

The ingot or slab of the alloy of the invention may be provided with a cladding on either or both sides thereof and this composite is then processed in accordance with the invention. Such clad or composite products utilize a core of the aluminum base alloy of the invention and a cladding typically of higher purity alloy which corrosion protects the core. The cladding includes essentially unalloyed aluminum or aluminum containing not more than 0.1 or 1% of all other elements. Aluminum alloys herein designated 1XXX type refer to all Aluminum Association (AA) alloys having the number 1 as the first digit and thus include all 1000 types, 1100 types, 1200 types and 1300 types. It also is intended to encompass all other aluminum or aluminum base compositions that satisfy the AA registered composition limits for any AA alloy having 1 as the first digit in its AA designation. In general, 1XXX type aluminum or aluminum alloy can serve as the cladding. Thus, the cladding on the core may be selected from various Aluminum Association alloys such as 1060, 1045, 1100, 1200, 1230, 1135, 1235, 1435, 1145, 1345, 1250, 1350, 1170, 1175, 1180, 1185, 1285, 1188 or 1199. In addition, AA alloy 7072 containing zinc (0.8 to 1.3) can serve as the cladding and alloys such as 6003 or 6253 which contain more than 1% of alloying additions can serve as cladding. The cladding alloy is different than the core alloy and does not contain as much copper, preferably being free of substantial amounts of copper, not over 0.5 or 1%, preferably less than 0.2 or 0.3% Cu, which could interfere with corrosion protection. Other alloys could also be useful as cladding as long as they provide sufficient overall corrosion protection to the core alloy. The clad layer or layers are much thinner than the core, each constituting



5,213,639

5

1 to 15 or 20 or possibly 25% of the total composite thickness. A cladding layer more typically constitutes around 1 to 10% or so of the total composite thickness.

In addition to or in lieu of an aluminum or aluminum alloy cladding, a chemical, electrochemical or other coating or surface treatment can be used to improve corrosion resistance if desired, although cladding is presently preferred.

The alloy stock may be homogenized prior to hot working or it may be heated and directly hot rolled. If homogenization is used, it may be carried out by heating to a metal temperature in the range of 900° or 910° or 920° F. to 945° or 950° or 960° F. or, possibly as much as 1000° F., for a period of time of at least 1 hour to dissolve soluble elements and to homogenize the internal structure of the metal. It is to be understood that temperatures substantially above 945° or 950° or 960° F., for instance a temperature of 975° or 980° or 1000° F., introduce significant risk of damaging the metal and are preferably avoided. A suitable time period is about 4 hours or more in the homogenization temperature range. Normally, the soak time at the homogenizing temperature does not have to extend for more than 8 hours, however, longer times are not normally detrimental. Four to six hours at the homogenization temperature has been found to be quite suitable. A typical homogenization temperature is 920° F.

For purposes of the present invention, it can be preferred to initially hot roll a clad ingot composite without a full homogenizing. Thus, the ingot can be heated to 800° or 850° to 900° or 950° F. for a short time (or to 900° to 950° F. for a longer time in the case of homogenization) and hot worked or hot rolled to provide an intermediate gauge product, typically a slab. Hot rolling is performed wherein the starting temperature for rolling is in the range of 600° to 900° F., or even possibly higher provided melting or other ingot damage is avoided. When the use of the alloy is for fuselage skins, for example, the hot rolling is typically performed on ingot or starting stock 15 to 20 or more inches thick to provide an intermediate product or slab having a thickness of about 2 or 3 to 8 inches, the typical reductions being 40 or 50 or 60% to about 80% or more.

After hot rolling, the intermediate gauge product or slab is subjected to a reheating step. This reheating step is quite important to the present invention, particularly with respect to minimizing or avoiding soluble constituent or secondary phase particles and improving fatigue crack growth resistance and fracture toughness. Thus, in the reheating step, the intermediate gauge product or hot rolled slab is heated to a temperature of at least about 900°, or possibly a lower temperature such as 895° or maybe 890° on a somewhat less preferred basis, to a temperature of about 920° or 930° F., for example, which is near or above the solvus temperature of secondary phase particles, to dissolve or partially dissolve soluble constituents that remain from casting or may have precipitated during the preceding hot rolling. Such constituent particles include  $Al_2CuMg$ ,  $Al_2Cu$ , for example. The reheating has the effect of putting most of the Cu and Mg into solid solution. The heating can be in the range of 900° to 945° F., or possibly 950° or possibly as much as 960° F., with a preferred range being 900° or 910° to 930° F. or 940° F. It is repeated that temperatures substantially above 945° or 950° F. introduce risk of damaging the metal and decreasing the advantages achieved in practicing the invention, it being added that the reheating operation is even less tolerant of excessive

6

temperature than homogenization or heating before the first hot rolling. A reheating temperature of 975° or 980° F. could damage the metal because non-equilibrium eutectic melting would initiate or occur. Hence, such excessive temperatures are preferably avoided in practicing the invention, especially in both the reheat step and in subsequent operations such as solution heat treating where maximum temperatures are preferably limited to about 950° or 955° F., and more preferably, do not exceed 940° or 945° F., better yet not over 935° F., especially for metal which is derived from large DC cast ingots which can contain pockets having richer concentrations of alloying elements such as copper, a condition which might be relieved some by spray casting or other ingot production techniques. In the reheating operation, the intermediate gauge product can be held for about 20 minutes (or possibly 10 minutes) or one half or 1 hour to about 40 hours when the metal is in the aforesaid temperature range or near or above the solvus temperature for the soluble elements or phases. Preferably, times at said metal temperature of 900° F. or more are more than 2 hours, for instance in the range of 3 or more, preferably 4 hours or more to about 24 hours for metal derived from DC casting. It is important that the reheat is carefully controlled within the parameters set forth. If the reheating operation is substantially lower than 900° F., for example, 850° F., this can leave large volumes of coarse undissolved  $Al_2CuMg$  and  $Al_2Cu$  particles, for example, which particles can have an adverse effect on the fatigue crack growth resistance in the final product. In fact, if the reheat is below the solvus temperature, these particles can even grow in size. The presence of such particles can limit crack propagation resistance in the final sheet product.

In clad products, the temperature and duration of the reheat is very important for another reason. If the reheat temperature is excessive or if the time at reheat temperature is excessive, copper can diffuse into the higher purity aluminum cladding. This diffusion can detrimentally affect the corrosion protection afforded by the cladding. The present invention serves to both increase the dissolution of the deleterious constituent particles and yet avoid excessive high temperature thermal exposure times that can cause copper diffusion into the cladding, or at least keep diffusion within acceptable levels.

After the reheat, the intermediate product or slab is subjected to a second hot rolling operation. The second hot rolling operation is performed in the temperature range of about 500 to 900° F., preferably 600° to 850° F. In general, this is effected by moving the metal from the reheating furnace to the rolling station without the need for a separate cooling operation which could even be harmful if it involved substantial times at temperatures within 800° or 820° to 870° or 880° F. The hot rolling may be performed to a final gauge, e.g., 0.5 inch or less. Alternatively, the hot rolling step can be performed to provide a second intermediate product, typically sheet, having a thickness in the range of 0.1 to 0.25 or 0.3 inch or more. Thereafter, the second intermediate product can be cold rolled to a final gauge typically in the range of 0.01 or 0.05 to about 0.2 inch, but possibly up to about one-half inch, to produce a substantially or largely recrystallized product. An intermediate anneal may be used before cold rolling, if desired. Alternatively the product can be hot rolled to a final thickness of 0.1 or 0.2 or 0.3 inch or up to about  $\frac{1}{2}$  inch or a little more such as up to around  $\frac{3}{4}$  inch without cold rolling.

5,213,639

7

Even though hot rolling can proceed within 600° to 900° F., once the reheat step is performed effort preferably should be made to avoid prolonged exposure to temperatures substantially above 700° or 750° F. and substantially below around 900°, for instance temperatures around 850° or even 800° F. should be avoided for prolonged exposures although the relatively brief exposures encountered in hot rolling are not considered excessive. Such temperatures (for instance around 800° or 825° to 875° F. or so), if encountered for substantial time, result in lowered toughness and higher fatigue crack growth rate. Hence, the practice of the invention preferably includes measures consistent with plant practicalities and economics to avoid substantial time exposures (for example exceeding about 3 to 1 hour) at temperatures of about 780° or 800° or more to 870° or so, after the aforesaid reheating step (at 900° or 910° to about 945° or 950° F.) used in practicing the invention.

After rolling, the sheet product is subjected to a solution heat treatment preferably in the range of about 900° or 910° to 945° or 950° F., more preferably 905° to 935° or 940° F. It can be important that the solution heat treatment be carefully controlled in duration. Thus, the solution heat treatment can be accomplished in 5 minutes or even less when the metal has reached the solution temperature. The time can be extended to 15 minutes or even 60 minutes or possibly longer especially with a non-clad product. However, in clad product, care should be taken against diffusion of copper into the cladding and possible problems resulting therefrom and shorter times favor less diffusion.

Solution heat treatment in accordance with the present invention may be performed on a continuous basis. Basically, solution effects can occur fairly rapidly. In continuous treating, the sheet is passed continuously as a single web through an elongated furnace which greatly increases the heat-up rate. Long solution heat treat times may be used to dissolve the soluble constituents such as  $Al_2CuMg$  and  $Al_2Cu$ . However, long time (more than 1 hour or 2 hours) solution heat treatments should not be used on clad products because of the excessive Cu diffusion that can occur in the cladding. The continuous approach facilitates practice of the invention since a relatively rapid heat-up and short dwell time at solution temperature result in minimizing copper diffusion into the cladding. Accordingly, solution heat treating in as little as about 10 minutes, or less, for instance about 0.5 to 4 minutes, are useful in practicing the invention, especially for thin members with thin cladding. As a further aid to achieving a short heat-up time, a furnace temperature or a furnace zone temperature significantly above the desired metal temperatures provides a greater temperature head useful to speed heat-up times.

After solution heat treatment, it is important that the metal be rapidly cooled, or quenched, to prevent or minimize the uncontrolled precipitation of secondary phases, e.g.,  $Al_2CuMg$  and  $Al_2Cu$ . Thus, it is preferred in the practice of the invention that the quench rate be at least 100° F./sec from solution temperature to a temperature of 350° F. or lower. A preferred quench rate is at least 300° F./sec in the temperature range of 925° F. or more to 350° F. or less. Suitable rates can be achieved with the use of water, e.g., water immersion or water jets. Further, air or air jets may be employed.

After quenching, the sheet may be cold worked, for example, by stretching or cold rolling, or both, by up to about 10% of its original length. Typically, cold or

8

other working may be employed which produces a working effect similar to (or substantially, i.e. approximately, equivalent to) that which would be imparted by stretching at room temperature in the range of about ½% or 1% or 1½% to 2% or up to 4 or 6% or 8% of the products' original length. Stretching or other cold working such as cold rolling about 2 or 3 to 9 or 10%, preferably about 4 or 5% to about 7 or 8%, can improve strength while retaining good toughness. Yield strength can be increased around 10 ksi, for instance to levels as high as around 59 or 60 ksi or more without excessively degrading toughness, even actually increasing toughness by 5 or 6 ksi/in ( $K_{IC}$  in L-T orientation), in one test by stretching 6 or 7%. The invention in heavy sheet form, for instance, about 0.2 or 0.25 inch thick, can be stretched 6 or 7% with relative ease and gain about 10 ksi strength along with a toughness gain of about 5 or so ksi/in, or at least no degradation in toughness, or an acceptable relatively small degradation in toughness, the strength gain being significant. Cold working before aging is easier because the metal is weaker but can encounter Leuder's lines if stretching is used. Cold working after significant aging effect (for instance, a significant strength increase) requires more power because the metal is stronger but involves less likelihood of Leuder's lines or the like.

After rapidly quenching, and cold working if desired, the sheet product is aged, preferably naturally aged. By natural aging is meant to include aging at room temperature, for instance 75° F. or so, or 70° to 80° F. or so, and temperatures up to around 175° F. or 200° F. Aging at room temperature (75° F.) reaches 90% or so of its practical naturally aged strength potential within about 24 or 30 hours or so. If cold work is employed, it can precede natural aging or follow some amount thereof as stated above. Artificial aging practices which do not excessively reduce fracture toughness or fatigue crack growth resistance could also be used. For instance, aging at around 200° to 215° or 220° F. or so for 12 to 8 hours or so, or at around 280° to 300° F. or so for around an hour or so could be suitable. However, excessive combination of aging time and temperature could increase strength at an excessive penalty in toughness or fatigue resistance, or both.

If artificial aging is employed, it is believed such could be combined with a forming or shaping operation. Such age forming using a load at elevated artificial aging temperature to bend or otherwise plastically form a shaped or partially shaped product is believed to be useful in practicing the invention although excessive aging time or temperature should be avoided as stated just above. Accordingly, the invention includes combining forming and artificial aging although the toughness and fatigue crack growth rate properties could be diminished some by such. Nonetheless, it is believed that the invention products would substantially outperform age formed 2024 products with respect to the property combinations discussed herein, good combinations of strength, along with toughness or fatigue crack growth resistance, or both.

The improved product could be provided to a user in a non-solution heat treated condition, such as annealed "O" temper, and then formed and solution heat treated and aged by the user.

Conforming to these controls and using the alloy composition of the invention greatly aids the production of sheet stock having high yield strength, similar to 2024 in T3 temper, along with substantially improved



levels of fracture toughness and increased resistance to fatigue crack growth and high resistance to corrosion. The above-described controls for heating and rolling impart a substantial improvement in combination with the herein-described composition controls. That is, sheet can be produced having a minimum long transverse yield strength of about 37 or 38 ksi or 39 or 40 or 42 ksi, for instance about 43 or 44 ksi or 45 or 46 or 47 ksi, along with good minimum (guaranteeable)  $K_{Ic}$  fracture toughness or good maximum (guaranteeable) fatigue crack growth rate, or both. A long transverse yield strength over 55 ksi can be achieved if the product is cold worked, such as by stretching, after quenching. Minimum yield strength could increase to 50 ksi or more, for instance 52 or 54 ksi or more, if cold working is used after quenching.

When referring to a minimum (for instance for strength or toughness) or to a maximum (for instance for fatigue crack growth rate), such refers to a level at which specifications for materials can be written or a level at which a material can be guaranteed or a level that an airframe builder (subject to safety factor) can rely on in design. In some cases, it can have a statistical basis wherein 99% of the product conforms or is expected to conform with 95% confidence using standard statistical methods.

FIGS. 1 and 2 illustrate the extent of improvement in  $K_{Ic}$  toughness (FIG. 1) and fatigue crack growth rate (FIG. 2) of the invention over 2024 type alloy in T3 temper. Alloy 2024 is the present fuselage alloy for airliners. FIG. 1 includes a point ( $K_{Ic}$  within square) showing 2024 that had been processed according to the process of the invention. FIG. 2 shows the invention product versus 2024 that had been processed according to the invention method which enhanced its fatigue performance somewhat. The extent of the improvement for the invention is pronounced, even over 2024 that had been subjected to improved processing in accordance with the invention.

Fracture toughness is an important property to airframe designers, particularly if good toughness can be combined with good strength. By way of comparison, the tensile strength, or ability to sustain load without fracturing, of a structural component under a tensile load can be defined as the load divided by the area of the smallest section of the component perpendicular to the tensile load (net section stress). For a simple, straight-sided structure, the strength of the section is readily related to the breaking or tensile strength of a smooth tensile coupon. This is how tension testing is done. However, for a structure containing a crack or crack-like defect, the strength of a structural component depends on the length of the crack, the geometry of the structural component, and a property of the material known as the fracture toughness. Fracture toughness can be thought of as the resistance of a material to the harmful or even catastrophic propagation of a crack under a tensile load.

Fracture toughness can be measured in several ways. One way is to load in tension a test coupon containing a crack. The load required to fracture the test coupon divided by its net section area (the cross-sectional area less the area containing the crack) is known as the residual strength with units of thousands of pounds force per unit area (ksi). When the strength of the material as well as the specimen are constant, the residual strength is a measure of the fracture toughness of the material. Because it is so dependent on strength and geometry, re-

sidual strength is usually used as a measure of fracture toughness when other methods are not as useful because of some constraint like size or shape of the available material.

When the geometry of a structural component is such that it doesn't deform plastically through the thickness when a tension load is applied (plane-strain deformation), fracture toughness is often measured as plane-strain fracture toughness,  $K_{Ic}$ . This normally applies to relatively thick products or sections, for instance 0.6 or 0.75 or 1 inch or more. The ASTM has established a standard test using a fatigue pre-cracked compact tension specimen to measure  $K_{Ic}$  which has the units ksi $\sqrt{\text{in}}$ . This test is usually used to measure fracture toughness when the material is thick because it is believed to be independent of specimen geometry as long as appropriate standards for width, crack length and thickness are met. The symbol  $K$ , as used in  $K_{Ic}$ , is referred to as the stress intensity factor. A narrower test specimen width is sometimes used for thick sections and a wider test specimen width for thinner products.

Structural components which deform by plane-strain are relatively thick as indicated above. Thinner structural components (less than 0.6 to 0.75 inch thick) usually deform under plane stress or more usually under a mixed mode condition. Measuring fracture toughness under this condition can introduce variables because the number which results from the test depends to some extent on the geometry of the test coupon. One test method is to apply a continuously increasing load to a rectangular test coupon containing a crack. A plot of stress intensity versus crack extension known as an R-curve (crack resistance curve) can be obtained this way. The load at a particular amount of crack extension based on a 25% secant offset in the load vs. crack extension curve and the crack length at that load are used to calculate a measure of fracture toughness known as  $K_{R25}$ . It also has the units of ksi $\sqrt{\text{in}}$ . ASTM E561 (incorporated by reference) concerns R-curve determination.

When the geometry of the alloy product or structural component is such that it permits deformation plastically through its thickness when a tension load is applied, fracture toughness is often measured as plane-stress fracture toughness. The fracture toughness measure uses the maximum load generated on a relatively thin, wide pre-cracked specimen. When the crack length at the maximum load is used to calculate the stress-intensity factor at that load, the stress-intensity factor is referred to as plane-stress fracture toughness  $K_{Ic}$ . When the stress-intensity factor is calculated using the crack length before the load is applied, however, the result of the calculation is known as the apparent fracture toughness,  $K_{app}$ , of the material. Because the crack length in the calculation of  $K_{Ic}$  is usually longer, values for  $K_{Ic}$  are usually higher than  $K_{app}$  for a given material. Both of these measures of fracture toughness are expressed in the units ksi $\sqrt{\text{in}}$ . For tough materials, the numerical values generated by such tests generally increase as the width of the specimen increases or its thickness decreases.

Plane-stress fracture toughness can be determined from a center cracked tension test. In this test, sheet in accordance with the invention exhibits a minimum  $K_{app}$  of about 80 to 85 ksi $\sqrt{\text{in}}$ , preferably 85 to 90 or 95 or more, even 100 or more, ksi $\sqrt{\text{in}}$  (that is, 80 or more up to 100 or more ksi $\sqrt{\text{in}}$ ) when tested with an approximately 16-inch wide test specimen, and a minimum  $K_{Ic}$

5,213,639

11

within about 140 to 145, preferably within about 150 to 160 ksi√in or more, even 165 or more (that is, 140 or more up to 165 or more ksi√in). It is to be appreciated that the width of the test panel used in a toughness test can have a substantial influence on the stress intensity measured in the test. A given material may exhibit a  $K_{c_{app}}$  toughness of 60 ksi√in using a 6-inch wide test specimen, whereas for wider specimens the measured  $K_{c_{app}}$  will increase with wider and wider specimens. For instance, the same material that had a 60 ksi√in  $K_{c_{app}}$  toughness with a 6-inch panel could exhibit a higher  $K_{c_{app}}$ , for instance around 90 ksi√in, in a 16-inch panel and still higher  $K_{c_{app}}$ , for instance around 150 ksi√in, in a 48-inch wide panel test and a still higher  $K_{c_{app}}$ , for instance around 180 ksi√in, with a 60-inch wide panel test specimen. Accordingly, in referring to  $K$  values for toughness tests herein, unless indicated otherwise, such refers to testing with a 16-inch wide panel. However, those skilled in the art recognize that test results can vary depending on the test panel width and it is intended to encompass all such tests in referring to toughness. Hence, toughness substantially equivalent to or substantially corresponding to a minimum value for  $K_c$  or  $K_{c_{app}}$  in characterizing the invention products, while largely referring to a test with a 16-inch panel, is intended to embrace variations in  $K_c$  or  $K_{c_{app}}$  encountered in using different width panels as those skilled in the art will appreciate. It should be noted that toughness of prior commercially produced 2024-T3 alloy was not normally guaranteed or even routinely required to be tested; however, typical  $K_c$  values (from 16" wide specimen) for conventional 2024-T3 are generally about 125 ksi√in, but  $K_c$  values (T-L orientation) as low as 115 ksi√in and even below 110 ksi√in have been measured, all of which are well below 140 to 165 ksi or more for the minimum  $K_c$  for the invention product. Typical  $K_{c_{app}}$  values for 2024 using 16-inch wide test specimens are in the 70's (ksi√in) or possibly higher, but well below the levels reached with the invention. The plane-stress fracture toughness ( $K_{c_{app}}$ ) test applies to all thicknesses of products but may in some applications find more use in thinner products such as 1 inch or  $\frac{1}{2}$  inch or less in thickness, for example,  $\frac{1}{4}$  inch or  $\frac{1}{8}$  inch or less in thickness. The specimens for the immediately preceding tests are usually in the T-L orientation (specimen length perpendicular to rolling direction and crack parallel to the rolling direction). The testing typically is in accordance with ASTM E561 and ASTM B646 (both incorporated herein by reference).

The toughness of the improved products according to the invention is so high that it allows the aircraft designer's focus for a material's damage tolerance to switch some from toughness measurement to fatigue crack growth rate which, in its own right, is an important property. Resistance to cracking by fatigue is a very desirable property. The fatigue cracking referred to occurs as a result of repeated loading and unloading cycles, or cycling between a high and a low load such as when a wing moves up and down or a fuselage swells with pressurization and contracts with depressurization. The loads during fatigue are below the static ultimate or tensile strength of the material measured in a tensile test and they are typically below the yield strength of the material. If a crack or crack-like defect exists in a structure, repeated cyclic or fatigue loading can cause the crack to grow. This is referred to as fatigue crack propagation. Propagation of a crack by fatigue may lead to a crack large enough to propagate catastrophically

12

when the combination of crack size and loads are sufficient to exceed the material's fracture toughness. Thus, an increase in the resistance of a material to crack propagation by fatigue offers substantial benefits to aerospace structure longevity. The slower a crack propagates, the better. A rapidly propagating crack in an airplane structural member can lead to catastrophic failure without adequate time for detection, whereas a slowly propagating crack allows time for detection and corrective action or repair.

The rate at which a crack in a material propagates during cyclic loading is influenced by the length of the crack. Another important factor is the difference between the maximum and the minimum loads between which the structure is cycled. One measurement including the effects of crack length and the difference between maximum and minimum loads is called the cyclic stress intensity factor range or  $\Delta K$ , having units of ksi√in, similar to the stress intensity factor used to measure fracture toughness. The stress intensity factor range ( $\Delta K$ ) is the difference between the stress intensity factors at the maximum and minimum loads. Another measure affecting fatigue crack propagation is the ratio between the minimum and the maximum loads during cycling, and this is called the stress ratio and is denoted by  $R$ , a ratio of 0.1 meaning that the maximum load is 10 times the minimum load.

The fatigue crack propagation rate can be measured for a material using a test coupon containing a crack. One such test specimen or coupon is about 12 inches long by 4 inches wide having a notch in its center extending in a cross-wise direction (across the width; normal to the length). The notch is about 0.032 inch wide and about 0.2 inch long including a 60° bevel at each end of the slot. The test coupon is subjected to cyclic loading and the crack grows at the end(s) of the notch. After the crack reaches a predetermined length, the length of the crack is measured periodically. The crack growth rate can be calculated for a given increment of crack extension by dividing the change in crack length (called  $\Delta a$ ) by the number of loading cycles ( $\Delta N$ ) which resulted in that amount of crack growth. The

crack propagation rate is represented by  $\Delta a/\Delta N$  or 'da/dN' and has units of inches/cycle. The fatigue crack propagation rates of a material can be determined from a center cracked tension panel. The fatigue crack propagation rates for sheet in accordance with the invention are much slower than the prior 2024-T3 alloy sheet made by standard production methods when measured using a center cracked tension panel and tested at cyclic stress intensity factors of  $\Delta K$  greater than 5 ksi√in. FIG. 2a shows the fraction obtained by dividing the fatigue crack propagation rate of sheet according to the invention by the fatigue crack propagation rate of 2024-T3 alloy sheet, which fraction is plotted versus the cyclic stress intensity factor range,  $\Delta K$ . In FIG. 2a, a ratio of 1 indicates equal fatigue crack growth rate whereas a ratio of 0.5 indicates much superior performance (half the crack growth rate, or twice as good). The data show that the fatigue crack propagation rates of the invention product sheet are dramatically reduced when compared to 2024-T3 sheet especially at higher values of  $\Delta K$ . For example, at  $\Delta K=25$  ksi√in, the fatigue crack propagation rate of the sheet according to the invention is less than one half of the crack propagation rate of 2024-T3 alloy sheet. That is, a crack in 2024-T3 alloy sheet will grow more than twice as fast as a crack in the invention product sheet when subjected

5,213,639

13

to loads such that the cyclic stress intensity factor range  $\Delta K$  is 25 ksi $\sqrt{\text{in}}$ . At  $\Delta K=30$  ksi $\sqrt{\text{in}}$ , the fatigue crack growth rate for sheet according to the invention is substantially less than 40% of the crack growth rate for 2024-T3; that is, fatigue cracks in 2024 grow two-and-a-half (2½) times faster than in the invention sheet.

In a constant load amplitude test, the tensile load or pull loads for high load and low load are the same through the fatigue cycling. This causes the  $\Delta K$  level in terms of stress intensity (ksi $\sqrt{\text{in}}$ ) to increase as the crack grows during the test. This increase becomes more rapid as the test progresses, and the precision can thereby suffer in later stages as the crack grows significantly in length.

Still another technique in testing is use of a constant  $\Delta K$  gradient. In this technique, the otherwise constant amplitude load is reduced toward the latter stages of the test to slow down the rate of  $\Delta K$  increase. This adds a degree of precision by slowing down the time during which the crack grows to provide more measurement precision near the end of the test when the crack tends to grow faster. This technique allows the  $\Delta K$  to increase at a more constant rate than achieved in ordinary constant load amplitude testing.

Another way to measure fatigue crack propagation rate of sheet is by growing a crack at a constant level of the applied stress intensity factor range,  $\Delta K$ , throughout the test. The advantage of the constant  $\Delta K$  test is that it provides a repeated measure of the crack growth rate at that level of  $\Delta K$  for a relatively large distance of crack propagation. In this test, as the crack grows the tensile loads between which the panel is cycled need to be reduced as the test progresses to maintain a constant level of  $\Delta K$ . At the start of this test, an initial fatigue crack is grown from a small machined slot in the center of the panel at a low value of  $\Delta K$ , then the load is increased to give the desired level of  $\Delta K$ . When this is done, the crack propagates at an initial rate followed by a rapid decrease to a "steady state" crack propagation rate which normally is the propagation rate measured in the test. One reason for this decrease in propagation rate is believed to be the development of what is referred to as crack closure. Crack closure can occur during the unloading portion of the fatigue cycle when the crack faces come into contact with one another before the load drops to the minimum load level. Because the crack closes at a load above the minimum load, further unloading has no effect on the crack. Thus, the difference between the minimum and maximum loads which affect the crack is reduced which results in a lower effective  $\Delta K$  than the intended or nominal applied  $\Delta K$ . As a consequence, when crack closure occurs, the crack growth rate of the material is decreased. Several causes of closure are rough fracture surfaces that do not fit back together exactly during unloading, oxide buildup on the fracture surfaces that come into contact during unloading, or material at the crack tip is stretched past the yield strength (or plastically deformed) and after the crack grows through the stretched material the crack faces come into contact during unloading because the material is stretched. The latter cause is referred to as plasticity induced closure and is the cause of the initial decrease in crack growth rate observed in the constant  $\Delta K$  test. After the crack has grown for some distance at a constant  $\Delta K$  the amount of crack closure becomes constant and a steady state crack growth rate results.

When the invention product sheet is tested using a 4-inch wide panel with a center crack at a constant level

14

of the cyclic stress intensity factor range of  $\Delta K=25$  ksi $\sqrt{\text{in}}$ , a stress ratio of  $R=-0.1$ , in air with a relative humidity greater than 95%, the average steady state fatigue crack propagation rate for sheet according to the invention is  $5.54 \times 10^{-5}$ , while for commercial 2024-T3 sheet tested under the same conditions the average fatigue crack propagation rate is almost twice as fast at  $10.6 \times 10^{-5}$ . Similarly when tested at a constant cyclic stress intensity factor range of  $\Delta K=30$  ksi $\sqrt{\text{in}}$  and the same conditions as above, the average steady state fatigue crack propagation rate for the invention sheet is  $9.55 \times 10^{-5}$  and for 2024-T3 sheet the average fatigue crack propagation rate is more than twice as fast  $21.4 \times 10^{-5}$ . At  $\Delta K$  of about 22 ksi $\sqrt{\text{in}}$ , the sheet according to the invention had an average steady state fatigue crack propagation rate of  $5 \times 10^{-5}$  which was around half that for commercial 2024-T3 sheet. The specimens for the immediately preceding tests are usually in the T-L orientation. The testing is in accordance with ASTM E647-88, the entire content of which is incorporated herein by reference.

As shown in FIG. 2, the new product has very good resistance to fatigue crack propagation in tests conducted using a constant cyclic stress intensity factor range of 22 ksi $\sqrt{\text{in}}$ . This cyclic stress intensity factor range is important for the damage tolerant design of transport airplanes such as commercial airliners, but a  $\Delta K$  of 25 or 30 is also important in testing fatigue crack growth rate for aircraft application. Incidentally, in plots like FIG. 2 wherein crack length is shown on the horizontal axis and  $da/dN$  on the vertical axis, it is common for the data points on the extreme left (near the vertical axis) representing the rate at the early stage of testing to be higher than the steady state data shown in FIG. 2. The steady state data is often that of more importance.

#### Example 1

This example includes two parts. In Part 1, a 16×60 inch ingot containing, in accordance with the invention, 4.28% Cu, 1.38% Mg, 0.50% Mn, 0.07% Fe, 0.05% Si, balance Al was cast. The metal was clad with AA1145 then heated to approximately 875° F. and hot rolled to a slab gauge of 4.5 inches. The rolled slab was then heated to a temperature above 910° F. for 17 hours and hot rolled to a gauge of 0.176 inch. The metal was cold rolled to a final gauge of 0.100 inch before solution heat treating for 10 minutes at 925° F., quenched by cold water sprays, and stretched around 2%. The sheet was aged for 3 weeks at room temperature.

In Part 2, for comparison, an alloy with 2024 composition, 2024 being the alloy currently used for the fuselage skins of commercial jet airliners, having the approximate composition 4.6% Cu, 1.5% Mg, 0.6% Mn, 0.2% Fe, 0.1% Si, balance Al (actual composition: 4.54% Cu, 1.52% Mg, 0.64% Mn, 0.17% Fe, 0.08% Si), was processed essentially the same. It is to be noted that the 2024 comparison product does not represent typical commercial 2024 because the comparison product received processing according to the invention.

The product of the invention had a 16% higher plane stress fracture toughness ( $K_{IC}=156.5$  ksi $\sqrt{\text{in}}$  in average for 2 measurements of new product data of FIG. 1 versus 134.7 ksi $\sqrt{\text{in}}$  for the comparison special processed 2024 T-3 point of FIG. 1), and even greater improvement (around 25%) over normal 2024. Fatigue cracks for the invention product at a cyclic stress intensity range of 22 ksi $\sqrt{\text{in}}$  grew more than 44% slower



5,213,639

15

( $da/dN = 5.3 \times 10^{-5}$  in/cycle versus  $9.52 \times 10^{-5}$  in/cycle,

$$\frac{9.52 - 5.3}{9.52} = 44.33\%$$

as shown in the table below as compared to 2024 alloy even as processed according to the invention method to have better performance.

TABLE I

Fatigue Crack Propagation at Different Cyclic Stress Intensity Ranges		
Sample	$\Delta K$	$da/dN$
New Product	10	$6.70 \times 10^{-6}$
	22	$5.30 \times 10^{-5}$
	30	$1.34 \times 10^{-4}$
Specially processed 2024-T3	10	$7.91 \times 10^{-6}$
	22	$9.52 \times 10^{-5}$
	30	$3.71 \times 10^{-4}$

$\Delta K$  = Cyclic Stress Intensity Factor Range  
 $da/dN$  = Length of crack growth during one load/unload cycle. Test performed with an R-ratio (min. load/max. load) equal to 0.33

Fracture toughness was measured using a 16-inch wide, 44-inch long panel. All values given were taken in the T-L orientation which means that the applied load was parallel to the transverse direction of the sheet and the crack propagated parallel to the longitudinal direction of the sheet. Fatigue crack growth resistance was measured as the length a crack propagates during each cycle at a given stress intensity range. The measurements were made with an R-ratio of 0.33 in the T-L orientation. It is readily seen that as the stress intensity factor increases, the extent of the improvement becomes more prominent.

One possible explanation of part of the metallurgical causes of the improvement can be seen in FIGS. 3 and 4 which show differential scanning calorimetry curves. Differential scanning calorimetry offers a way to characterize the amount of coarse  $Al_2CuMg$  and  $Al_2Cu$  constituent particles. Because the eutectic is comprised of these phases with aluminum melts between 500° and 580° C., the energy associated with the melting reaction is related to the volume fraction of the particles. Prior alloy 2024 products typically exhibit a value greater than 2.2 calories/gram for the energy of fusion associated with melting three phases. Sheet material of the invention generally has a 500° to 580° C. differential scanning calorimetry peak of less than 1.0 cal/gram. FIGS. 3 and 4 show a comparison between the new product and 2024-T3 (which is the current material of choice for the fuselage skins of commercial jet aircraft) except that this particular 2024-T3 had been processed by special processing according to the invention which improved it over ordinary 2024.

Referring again to FIGS. 3 and 4 the size of the sharp peak that occurs in the temperature range of 500° to 530° C. (FIG. 3) is indicative of the amount of constituent phase or phases such as  $Al_2CuMg$  and  $Al_2Cu$  present. These phases are believed to contribute to the lowering of a material's fracture toughness and its resistance to fatigue crack growth. The new product (FIG. 4) has a much smaller peak indicating that the volume fraction of such constituent has been significantly reduced in accordance with the present invention.

Sheet material of the invention is preferably characterized by a substantial absence or sparsity of secondary phase particles, e.g.,  $Al_7Cu_2Fe$ ,  $Al_6(Fe, Mn) Al_2CuMg$  and  $Al_2Cu$  particles. That is, sheet material of the inven-

16

tion has generally not more than about 1.5 vol %, preferably not more than 1.25 vol %, of such particles larger than 0.15 square  $\mu m$  as measured by optical image analysis through a cross section of the product.

The volume fraction of total large constituent phase particles (including Fe and Si bearing particles), e.g., larger than 0.15 square  $\mu m$ , was much smaller for the new product than for the conventionally treated 2024-T3. In twelve measurements, the new product volume fraction ranged from 0.756% to 1.056%. In twelve measurements, the specially treated 2024-T3 constituent volume fraction ranged from 1.429% to 2.185%.

## EXAMPLE 2

This example includes four parts.

In Part 1 (see Example 1, Part 1, the Example 1 processing being repeated for reading convenience), a 16-inch thick by 60-inch wide ingot in accordance with the invention containing 4.28% Cu, 1.38% Mg, 0.50% Mn, 0.07% Fe, 0.05% Si, balance Al, was cast. The metal was clad with alloy 1145 then preheated to approximately 875° F. and hot rolled to a slab gauge of 4.5 inches. The slab was then reheated to a temperature above 910° F. for 17 hours and hot rolled to a gauge of 0.176 inch. The metal was cold rolled to a final gauge of 0.1 inch and solution heat treated for 10 minutes at 925° F., quenched and stretched around 2% in length. Then the sheet was naturally aged for 3-weeks at room temperature. The strength, plane stress fracture toughness and resistance to fatigue crack growth of the product of this invention are listed in the table below.

In Part 2, a 16-inch thick comparison ingot having a composition in accordance with the invention and containing 4.26% Cu, 1.37% Mg, 0.51% Mn, 0.08% Fe, 0.04% Si, balance Al, was cast. The metal was clad with alloy 1145 then it was given the same processing as described above for Part 1 except the 4.5 inch hot rolled slab was reheated to about 910° or 915° F. for about 8 hours, but then held at 850° F. for another 8 hours before the second hot rolling. In its final temper, this sheet had a lower combination of strength, toughness and resistance to fatigue crack growth than the product of this invention (see the table below). Specifically, the invention had a toughness 11.2% better than this comparison and this comparison's crack growth rate was 35% faster than that for the invention.

In Part 3 (see Example 1, Part 2, the processing being repeated for convenience in reading), a comparison ingot of 2024-T3, the alloy currently used for the fuselage skins of commercial jet airliners containing 4.54% Cu, 1.52% Mg, 0.64% Mn, 0.17% Fe, 0.08% Si, balance Al, was clad with alloy 1145 then was fabricated according to the process for the new product set forth above in Part 1 of this Example. This comparison material also had a lower combination of strength, toughness and resistance to fatigue crack growth than the product of this invention (see the table below). The invention had a 16% higher  $K_{IC}$  toughness and the comparison material's crack growth rate was over 61% faster than the invention product's at  $\Delta K = 25 \text{ ksi}\sqrt{\text{in}}$

$$\left( \frac{9.03 - 5.62}{5.62} = 61.56\% \right)$$

The table below also includes in Part 4 alloy 2024-T3 sheet clad with alloy 1145, the core 2024 containing

5,213,639

17

4.63% Cu, 1.58% Mg, 0.64% Mn, balance aluminum and impurities, using the standard 2024-T3 processing. The fatigue crack growth resistance and toughness of this sheet represent the typical behavior of the existing product that is currently used for fuselage skins of commercial aircraft.

These four sets of data (Parts 1 to 4) on commercial size product made from commercial size ingot emphasize how the damage-tolerant property improvements (fracture toughness and fatigue crack growth rate) can be achieved using the composition and process described in this invention. FIG. 5 illustrates strength versus toughness for Parts 1 to 4 of Example 2. Compared to 2024-T3, the product of this invention has over 33% higher T-L plane stress fracture  $K_{IC}$  toughness and the 2024 fatigue crack growth rate at a  $\Delta K$  of 25 was more than twice as fast as the invention product's. This shows the new product has clearly superior damage tolerant properties over the present 2024 T3 fuselage skin product. The data also show that, in order to achieve the optimum properties, it is important that both the composition and the process be in accordance with the invention.

TABLE II

EXAMPLE 2				
Example 2	Sample	Long Transverse Yield Strength	T-L Plane Stress Fracture Toughness $K_{IC}$	T-L $da/dN^a$
Part 1	Invention Product	46.6	156.5	$5.62 \times 10^{-5}$
Part 2	Invention Composition/ Low Temperature Hold Before Hot Roll	44.8	140.7	$7.6 \times 10^{-5}$
Part 3	2024 Composition/ Invention Processing	46.4	134.7	$9.08 \times 10^{-5}$
Part 4	2024-T3 Composition/ Low Temperature Reheat	43.8	117	$11.6 \times 10^{-5}$

<sup>a</sup>Test performed with an R-ratio (minimum load/maximum load) equal to 0.1 and constant  $\Delta K$  equal to 25 ksi $\sqrt{\text{in}}$ ;  $da/dN$  = Length of crack growth during one load/unload cycle. The test was a constant  $\Delta K$  test, i.e., the loads (max and min) are reduced as the crack length grows.

FIG. 6 shows typical strength versus toughness for the invention product in T3 temper and for commercial 2024-T3 for a number of commercial size lots for 0.1 inch thick sheet wherein it is clear that the invention product exhibits much better combinations of strength and T-L fracture toughness ( $K_{IC}$ ). In FIG. 6 all the 2024 exhibits  $K_{IC}$  toughness levels below 130 ksi $\sqrt{\text{in}}$  (and most below 125 ksi $\sqrt{\text{in}}$ ) whereas all the invention product exhibits  $K_{IC}$  above 130, above 135, above 140 and all equal to or exceed around 145 ksi $\sqrt{\text{in}}$ . All but one of the invention products had a  $K_{IC}$  level above 150 ksi $\sqrt{\text{in}}$  and all had yield strength equal to or above 45 ksi, whereas a substantial amount of the 2024 T3 had yield strength below 45 ksi.

FIG. 7 shows fatigue crack growth rate versus change in crack length for commercial size lots of the invention product in T3 temper versus commercial 2024-T3 for 0.1 inch thick sheet wherein it is clear that the fatigue crack growth rate for 2024 is much faster than (practically twice) the rate for the invention product.

18

The preferred maximum levels of fatigue crack growth rate for the invention product are shown in FIGS. 8 and 9 which delineate maximum crack growth rate levels for different  $\Delta K$  and R values. Each figure includes a family of curves for different R values: R=0, 0.06, 0.1, 0.33 and 0.5 being shown. For R values between two of these values the maximum  $da/dN$  fatigue crack growth rate can be interpolated by estimation along a line between the closest R curves in accordance with known practices. For instance in FIG. 8, at  $\Delta K=25$  and R=0.2, the maximum  $da/dN$  in accordance with the invention is found by interpolation between the R=0.1 and R=0.33 curves to be about  $1.5 \times 10^{-4}$ .

For FIG. 8, the tests are the constant  $\Delta K$  gradient test or the constant load test. For FIG. 9, the test is the constant  $\Delta K$  test at steady state. FIGS. 8a and 8b use curves (for R=0.1 and R=0.33) from FIG. 8 as the heavy solid lines and add light line curves representing typical 2024 data. Again, the improvement of the invention is very noticeable in that the maximum fatigue crack growth rates shown for the invention are considerably below typical rates for 2024.

FIGS. 8 and 9 are intended to broadly encompass performance for preferred products in the respective tests for FIG. 8 (constant  $\Delta K$  gradient/constant load) and FIG. 9 (constant  $\Delta K$  test). This is intended to encompass any one or more of various test conditions as to  $\Delta K$  or R (or both), for instance a constant  $\Delta K$  (FIG. 9) of 30 ksi and R=0.1. The invention product satisfies one or more of the test criteria shown in FIGS. 8 and 9, the invention encompasses products having a maximum fatigue crack growth rate as shown in FIG. 8 or 9 plus 5 or 10% or even 15%, especially at  $\Delta K$  levels of 15 or 20, or preferably above 20 ksi $\sqrt{\text{in}}$ , for instance 22 or 25 or 30 ksi $\sqrt{\text{in}}$ .  $\Delta K$ . Hence, reference to FIG. 8 or 9 in the appended claims refers to any one (or more) set of test conditions embraced in said figures to set the maximum fatigue crack growth rate for that set of conditions or specifications.

Tables III and IV are intended as a further aid in reading FIGS. 8 and 9.

TABLE III

Maximum Fatigue Crack Propagation Rates, $da/dN$ (in/cycle), of Invention Product at Selected Values of $\Delta K$ for the Constant K Gradient Test at Various R Ratios (FIG. 8)					
$\Delta K$ (ksi $\sqrt{\text{in}}$ )	$da/dN$ at R = 0	$da/dN$ at R = 0.06	$da/dN$ at R = 0.1	$da/dN$ at R = 0.33	$da/dN$ at R = 0.5
15	$1.36 \times 10^{-5}$	$1.59 \times 10^{-5}$	$2.10 \times 10^{-5}$	$2.68 \times 10^{-5}$	$3.43 \times 10^{-5}$
20	$3.38 \times 10^{-5}$	$3.79 \times 10^{-5}$	$5.26 \times 10^{-5}$	$7.44 \times 10^{-5}$	$1.18 \times 10^{-4}$
25	$6.52 \times 10^{-5}$	$7.44 \times 10^{-5}$	$1.28 \times 10^{-4}$	$1.93 \times 10^{-4}$	$3.73 \times 10^{-4}$

TABLE III-continued

Maximum Fatigue Crack Propagation Rates, $da/dN$ (in/cycle), of Invention Product at Selected Values of $\Delta K$ for the Constant $K$ Gradient Test at Various $R$ Ratios (FIG. 8)					
$\Delta K$ (ksi $\sqrt{\text{in.}}$ )	$da/dN$ at $R = 0$	$da/dN$ at $R = 0.05$	$da/dN$ at $R = 0.1$	$da/dN$ at $R = 0.33$	$da/dN$ at $R = 0.5$
30	$1.37 \times 10^{-4}$	$1.58 \times 10^{-4}$	$3.05 \times 10^{-4}$	$5.10 \times 10^{-4}$	$1.16 \times 10^{-3}$

TABLE IV

Maximum Fatigue Crack Propagation Rates, $da/dN$ (in/cycle), of Invention Product at Selected Values of $\Delta K$ for the Constant $\Delta K$ Gradient Test at Various $R$ Ratios (FIG. 9)				
$\Delta K$	$da/dN$ at $R = 0.05$	$da/dN$ at $R = 0.1$	$da/dN$ at $R = 0.33$	$da/dN$ at $R = 0.5$
15	$1.26 \times 10^{-5}$	$1.41 \times 10^{-5}$	$1.93 \times 10^{-5}$	$2.68 \times 10^{-5}$
20	$2.68 \times 10^{-5}$	$3.06 \times 10^{-5}$	$4.16 \times 10^{-5}$	$6.10 \times 10^{-5}$
25	$5.00 \times 10^{-5}$	$5.81 \times 10^{-5}$	$7.81 \times 10^{-5}$	$1.18 \times 10^{-4}$
30	$8.48 \times 10^{-5}$	$1.10 \times 10^{-4}$	$1.37 \times 10^{-4}$	$2.13 \times 10^{-4}$

One recent requirement for aircraft fuselage material is its fatigue crack growth rate ( $da/dN$ ) in a constant  $\Delta K$  test at a  $\Delta K$  of 30 ksi $\sqrt{\text{in.}}$  and a stress ratio  $R$  of 0.1 wherein the crack growth rate after crack stabilization is measured. In one series of such tests, the invention product has exhibited a maximum crack growth rate of less than about  $1.15 \times 10^{-4}$  inches per cycle at a test frequency of 2 Hz and a relative humidity exceeding 95%. In these tests, a standard center slot test specimen with a center slot 0.2 inch long is fatigue cycled at a low load to cause the crack to grow. When the crack grows to  $\frac{1}{8}$  inch long, the load is increased so that  $\Delta K = 30$  ksi $\sqrt{\text{in.}}$ . The test is continued at a constant  $\Delta K$  of 30 ksi $\sqrt{\text{in.}}$  until the crack reaches a length of one inch. The steady state fatigue crack propagation (following an initial higher rate) was measured as the crack grew from about 0.6 or 0.7 inch to about one inch long. Accordingly, it will be appreciated that the invention product can satisfy a maximum of  $1.8 \times 10^{-4}$ , or  $1.6 \times 10^{-4}$ , or preferably  $1.4 \times 10^{-4}$ , or more preferably  $1.2 \times 10^{-4}$  inches per cycle in this type test. That is, a specification maximum from about  $1.8 \times 10^{-4}$  inch per cycle down to  $1.2$  or  $1.15 \times 10^{-4}$  inch per cycle in this test is equaled or bettered by the invention product. Thus in a substantially constant  $\Delta K$  test wherein  $\Delta K$  is substantially about 30 ksi $\sqrt{\text{in.}}$  (for instance 27 or 28 to 32 ksi $\sqrt{\text{in.}}$  or 30 ksi $\sqrt{\text{in.}}$   $\pm 10$  or 15%) and  $R$  is substantially about 0.1 (for instance  $0.1 \pm 0.01$  or 0.02) the maximum fatigue crack growth rate for invention sheet product includes the levels just described for the substantially steady state part of the test.

The fatigue crack growth rate testing herein described was performed in a relative humidity (R.H.) of 95%. This high R.H. makes the test more severe and more precise over tests run in uncontrolled ambient conditions. FIG. 10 compares fatigue crack growth rate tests in 95% relative humidity versus ambient air for both the invention product and for 2024-T3 sheet. The difference attributed to ambient versus high R.H. test conditions becomes significant at  $\Delta K$ 's below about 25 ksi $\sqrt{\text{in.}}$  with the difference increasing as  $\Delta K$  decreases. For instance, at a  $\Delta K$  of 20 ksi $\sqrt{\text{in.}}$  2024-T3  $da/dN$  is a little above  $3 \times 10^{-5}$  inch/cycle for an ambient air test, whereas it increases to about  $5 \times 10^{-5}$  for a 95% R.H. test. At a  $\Delta K$  of 10 ksi $\sqrt{\text{in.}}$ , the  $da/dN$  figures for 2024-T3 are about  $3 \times 10^{-6}$  for ambient air and  $6 \times 10^{-6}$  for 95% R.H. test. At a  $\Delta K$  of 7, the difference is even greater; about  $8 \times 10^{-7}$  in air versus  $3.1 \times 10^{-6}$  in 95%

R.H. The table below further illustrates this difference

TABLE V

Alloy	Test Condition	$da/dN$		
		$\Delta K = 7$	$\Delta K = 10$	$\Delta K = 20$
2024-T3	Ambient	$8 \times 10^{-7}$	$3 \times 10^{-6}$	$3 \times 10^{-5}$
	95% R.H.	$3.1 \times 10^{-6}$	$6 \times 10^{-6}$	$5 \times 10^{-5}$
Improved Product	Ambient	$6.5 \times 10^{-7}$	$2 \times 10^{-6}$	$1.8 \times 10^{-5}$
	95% R.H.	$2.6 \times 10^{-6}$	$4.5 \times 10^{-6}$	$2.9 \times 10^{-5}$

Accordingly it can be preferable to conduct fatigue crack growth rate tests in an atmosphere having a relative humidity above 75 or 80%, preferably 85% or 90% minimum, more preferably around 95%, for instance 95%  $\pm 5\%$ .

Another factor that can influence fatigue crack growth rate test results is the frequency at which the loads are applied to the specimen in the test. This effect can be more pronounced at higher relative humidity levels in the test environment. For instance, a difference in test frequency may be minimal or virtually non-existent if the test is carried out in dry argon. However, where the test is carried out in 95% relative humidity air, a lower test frequency generally produces higher fatigue crack growth rates. Unless indicated otherwise, for the tests conducted herein, the following frequencies were employed in the fatigue crack growth rate tests, the frequency referring to the number of times per second the test specimen was cycled from low to high load level and back. For constant  $\Delta K$  tests, the frequency typically was approximately 5 Hz (5 cycles per second) for  $\Delta K$ 's other than 30 (about 2 Hz for  $\Delta K = 30$  ksi $\sqrt{\text{in.}}$ ), and for the constant  $\Delta K$  gradient tests, the frequency started at approximately 25 cycles per second, but as the crack grew to a substantial length, the number of cycles per second decreased to frequencies of as low as 5 cycles per second because of equipment limitations. As is readily apparent, it can be useful to account for differences in test conditions in comparing one test to another, and it will be appreciated that in construing the extent of the present invention and the claims appended hereto, adjustments for different test conditions may be needed to appreciate the broad scope of the invention. Accordingly, in referring to FIGS. 8 and 9 in the claims as setting maximum  $da/dN$  levels, it is intended to adjust such for differences in test conditions such as humidity, cycles per unit time, or any other influence, as well as interpreting for  $R$  values different than those shown.

The extent of the invention's improvement over conventionally produced 2024-T3 commercial products in toughness (measured as  $K_{IC}$  or as  $K_{Qpp}$ ) is at least 5 to 10%, ranging up to 20% or 30% or more. This enables guaranteeing a minimum level of toughness performance much higher than possible with conventional 2024, which normally was not specified to a minimum level of toughness, that is, toughness was not normally guaranteed for 2024.



21

5,213,639

The extent of the invention's improvement over conventionally produced 2024-T3 commercial products in reduced (lower) fatigue crack growth rate (a toughness related property) is pronounced, especially at medium to higher levels of  $\Delta K$  such as 7 ksi $\sqrt{\text{in}}$  to 15 ksi $\sqrt{\text{in}}$  or, even more importantly, at  $\Delta K$  levels above 15 ksi $\sqrt{\text{in}}$  such as  $\Delta K$  of 20 ksi $\sqrt{\text{in}}$  to 25 ksi $\sqrt{\text{in}}$  or 30 or more ksi $\sqrt{\text{in}}$   $\Delta K$  where the extent of the improvement grows with increasing  $\Delta K$ . The fatigue crack growth rate of the invention represents an improvement of at least 5 to 10 or 20% over 2024-T3 (crack grows at least 10 to 20% slower than for 2024-T3) and, especially at  $\Delta K$  levels above 20, the invention represents an improvement of at least 10% and up to 50% or even more (at 50% improvement a crack grows half as fast as for 2024-T3).

In referring to improvements over 2024 or over 2024-T3, such generally and preferably refers to similar product form, for instance plate versus plate, clad sheet versus clad sheet, or at least to 2024 product forms expected to have similar property levels to the product form being compared.

The significance of the higher toughness and better (lower) fatigue crack growth rate achieved with the invention is that the aircraft fuselage designer can save significant weight by reducing the thickness of fuselage sheet or even by redesigning the structure to eliminate or reduce straps or other auxiliary, or secondary, components which are sometimes attached to fuselage skin to reinforce against tearing. Such auxiliary components, which can be generically referred to as "crack stoppers", decrease the stress in a cracked portion of the fuselage so that the crack shouldn't propagate beyond a certain point. The product of the invention has a fracture toughness so high, and fatigue crack growth rate so low, that it can facilitate designs without such components, or at least reduced components, for example, a reduced number of, or lighter weight, "tear crack stopper" components, or both, or even elimination of such components, without having to add excessive thickness to the fuselage skin itself to compensate for the reduced reinforcement. Another advantage of the lower rate of growth of cracks by fatigue achieved by the invention is that it allows the aircraft users to increase the intervals between inspection for cracks and defects, thereby reducing the costs of the inspections and reducing costs of operation and increasing the value of the aircraft to the user. The invention product also provides for increasing the number of pressurization/depressurizing or other stressful cycles further reducing operation costs and enhancing the value of an aircraft. In addition, the toughness of the improved products is so high that the aircraft designer's focus for a material's robustness or damage tolerance can change from toughness measurements to fatigue crack growth rate.

Toughness and fatigue measuring and testing has been described in some particularity, it being understood that the aforesaid testing is intended to illustrate the good property levels of the invention but not necessarily in limitation thereof. For instance, other methods of testing may be developed over time and the good performance of the invention can be measured by those methods as well. It is to be understood that the invention product properties are generally or substantially equivalent to the described test results regardless of the particular test method used. It is to be understood that the herein described practices, especially preferred practices, impart to the invention alloy a condition

22

where it exhibits good property combinations useful in aerospace and other uses.

The invention provides products suitable for use in large airplanes, such as large commercial passenger and freight airplanes, or other aircraft or aerospace vehicles. Such products, themselves, are typically large, typically several feet in length, for instance 5 or 10 feet up to 25 or 30 feet or even 50 feet or more, and 2 to 6 or 7 feet or more wide. Yet even in these large sizes, the invention products achieve good property combinations. Hence, a particular advantage of the invention is sufficiently large size products to be suited to major structure components in aircraft, such as major aircraft fuselage components and possibly other components such as wing section, fuselage section, tail section (empennage). The invention sheet and plate product (generically referred to as rolled stock) can be shaped into a member for an airplane, such as a fuselage component or panel, or such as a wing component or panel, and the airplane can utilize the advantage of the invention as described. The shaping referred to can include bending, stretch forming, machining and other shaping operations known in the art for shaping panels or other members for aircraft, aerospace or other vehicles. Forming involving bending or other plastic deformation can be performed at room temperature or at elevated temperatures such as around 200° to 400° or so. If elevated temperatures are used in forming, such can be used in an artificial aging treatment as earlier described. The member can also include attached stiffeners or strengtheners such as structural beams attached by riveting or other means.

Unless indicated otherwise, the following definitions apply herein:

- a. The term "ksi" is equivalent to kilopounds per square inch.
- b. Percentages for a composition refer to % by weight.
- c. The term "ingot-derived" means solidified from liquid metal by a known or subsequently developed casting process rather than through powder metallurgy techniques. This term shall include, but not be limited to, direct chill casting, electromagnetic continuous casting, spray casting and any variations thereof.
- d. In stating a numerical range for an element of a composition or a temperature or other process matter or a property or an extent of improvement or any other matter herein, and apart from and in addition to the customary rules for rounding off numbers, such is intended to specifically designate and disclose each number, including each fraction and/or decimal, between the stated minimum and maximum for said range. (For example, a range of 1 to 10 discloses 1.1, 1.2 ... 1.9, 2, 2.1, 2.2 ... and so on, up to 10. Similarly, a range of 500 to 1000 discloses 501, 502 ... and so on, up to 1000, including every number and fraction or decimal therewithin.) "Up to x" means "x" and every number less than "x", for instance up to 5 discloses 0.01 ... 0.1 ... 1 and so on up to 5.

While the invention is described in terms of certain specifics and embodiments, the claims herein are intended to encompass all equivalents and everything encompassed within the spirit of the invention.

Having thus described the invention, what is claimed is:

1. A method of producing an aluminum product comprising:

23

5,213,639

(a) providing stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;

(b) hot working said stock;

(c) heating said stock above about 895° F. to less than 975° F.;

(d) hot rolling said stock;

(e) solution heat treating;

(f) cooling.

2. The method according to claim 1 wherein said alloy contains one or more elements from the group consisting of 0.02 to 0.4 % Zr, 0.01 to 0.5% V, 0.01 to 0.4% Hf, 0.01 to 0.2% Cr, 0.01 to 1% Ag and 0.01 to 0.5% Sc, percentages being by weight.

3. The method according to claim 1 wherein said alloy contains less than 0.25% Fe and less than 0.25% Si, percentages being by weight.

4. The method according to claim 1 wherein said alloy contains not more than about 0.15% Fe and not more than about 0.15% Si, percentages being by weight.

5. The method according to claim 1 wherein said heating in recitation (c) is within about 900° to less than 975° F.

6. The method according to claim 1 wherein said heating in recitation (c) is within about 900° to 960° F.

7. The method according to claim 1 wherein said heating in recitation (c) is within about 905° to 950° F.

8. The method according to claim 1 wherein said heating in recitation (c) is within about 910° to 945° F.

9. The method according to claim 1 wherein said heating and solution heat treating are within about 910° to 935° F.

10. The method according to claim 1 wherein said heating above about 895° F. is longer than 2 hours.

11. The method according to claim 1 wherein said heating above about 895° F. is 3 or more hours.

12. The method according to claim 7 wherein said heating within about 910° to 945° F. is 4 to 24 hours.

13. The method according to claim 1 wherein, after said cooling, a working effect is imparted substantially equivalent to stretching at least 1% at room temperature.

14. The method according to claim 1 wherein, after said cooling, a working effect is imparted substantially equivalent to stretching at least 3% at room temperature.

15. The method according to claim 1 wherein, after said cooling, a working effect is imparted substantially equivalent to stretching at least 4% at room temperature.

16. The method according to claim 1 wherein, after said cooling and at least some significant aging effect, a working effect is imparted substantially equivalent to stretching at least 1% at room temperature.

17. The method according to claim 13 wherein said working effect includes stretching.

18. The method according to claim 13 wherein said working effect includes cold rolling.

19. The method according to claim 1 wherein said method includes, after said cooling, artificially aging above room temperature.

20. The method according to claim 1 wherein said method includes, after said cooling, artificially aging above room temperature, and during said artificial aging, forming or deforming the metal.

24

21. The method according to claim 1 wherein, subsequent to said cooling, a forming or shaping operation is performed above room temperature.

22. A method of producing an aluminum sheet or plate product comprising:

(a) providing stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to less than 0.2% iron, about 0.01 to less than 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;

(b) hot rolling said stock;

(c) heating the hot rolled stock within about 900° to 965° F.;

(d) further hot rolling said stock;

(e) cold rolling said stock;

(f) solution heat treating.

23. The method according to claim 22 wherein said heating in recitation (c) and said solution heat treating are within about 905° to 950° F.

24. The method according to claim 22 wherein said alloy contains not more than about 0.15% Fe and not more than about 0.15% Si, percentages being by weight.

25. The method according to claim 22 wherein said alloy contains, by weight, not more than about 0.15% Fe and not more than about 0.15% Si and said heating in recitation (c) and said solution heat treating are within about 905° to 945° F and said sheet or plate is naturally aged.

26. The method according to claim 22 wherein said heating in recitation (c) is for at least 3 hours.

27. The method according to claim 22 wherein said heating in recitation (c) is for at least 4 hours.

28. A method of producing an aluminum sheet or plate product comprising:

(a) providing stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to less than 0.2% iron, about 0.01 to less than 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;

(b) hot rolling said stock;

(c) heating said hot rolled stock within about 900° to 965° F.;

(d) further hot rolling said stock;

(e) solution heat treating.

29. The method according to claim 28 wherein said heating and solution heat treating are within about 905° to 950° F.

30. The method according to claim 28 wherein said alloy contains, by weight, not more than about 0.15% Fe and not more than about 0.15% Si.

31. The method according to claim 28 wherein said alloy contains, by weight, not more than about 0.15% Fe and not more than about 0.15% Si and said heating and solution heat treating are within about 905° to 950° F. and said sheet or plate is naturally aged.

32. The method according to claim 28 wherein said heating is for at least 3 hours.

33. The method according to claim 28 wherein said heating is for more than 2 hours.

34. A method of producing a clad aluminum product comprising:

(a) providing stock comprising:

5,213,639

25

- (i) an aluminum alloy consisting essentially of, by weight, about 3.3 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;
- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot working said stock;
- (c) heating said stock within about 900° to less than 975° F;
- (d) further hot rolling said stock;
- (e) solution heat treating.
- 35. The method according to claim 34 wherein said alloy contains, by weight, not more than about 0.15% for Fe and not more than about 0.15% for Si.
- 36. The method according to claim 34 wherein said heating is within about 900° to 950° F.
- 37. The method according to claim 34 wherein both said heating and said solution heat treating are within about 905° to 950° F.
- 38. A method of producing a clad aluminum sheet or plate product comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing less than about 0.2% iron and less than about 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock;
  - (c) heating said stock within about 900° to 960° F;
  - (d) hot rolling said stock;
  - (e) cold rolling said stock;
  - (f) solution heat treating within about 900° to 950° F.
- 39. The method according to claim 38 wherein said hot rolling in recitation (b) reduces the thickness of the stock by at least 40%.
- 40. The method according to claim 38 wherein said alloy contains, by weight, 0.15% max. Fe and 0.15% max. Si.
- 41. The method according to claim 38 wherein said alloy contains, by weight, 0.15% max. Fe and 0.15% max. Si and said heating and solution heat treating are within about 905° to 950° F.
- 42. The method according to claim 38 wherein said heating is for at least 3 hours.
- 43. The method according to claim 38 wherein said heating is for at least 4 hours.
- 44. A method of producing a clad aluminum sheet or plate product comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock to a reduction in thickness of at least 40%;
  - (c) heating said stock within about 900° to 965° F;
  - (d) hot rolling said stock;
  - (e) solution heat treating at at least 900° F.

26

- 45. The method according to claim 44 wherein said heating and solution heat treating are within 905° to 950° F.
- 46. The method according to claim 44 wherein said alloy contains, by weight, 1.2 to 1.6% Mg.
- 47. The method according to claim 44 wherein said alloy contains, by weight, 1.2 to 1.6% Mg and 4 to 4.5% Cu.
- 48. The method according to claim 44 wherein said heating is for at least 3 hours.
- 49. The method according to claim 44 wherein said heating is for at least 4 hours.
- 50. A method of producing a clad aluminum product having good strength along with good fracture toughness or good resistance to fatigue crack growth, or both, said method comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.8% manganese, and containing about 0.01 to less than 0.2% iron, about 0.01 to less than 0.2% silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock;
  - (c) heating said stock to at least 900° F. but not so high a temperature as to prevent achieving the aforesaid properties;
  - (d) further hot rolling said stock;
  - (e) solution heat treating;
  - (f) cooling.
- 51. A method of producing a clad aluminum sheet or plate product comprising:
  - (a) providing stock comprising:
    - (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% max. iron and not more than about 0.15% max. silicon, the remainder substantially aluminum, incidental elements and impurities;
    - (ii) a cladding thereon of a different aluminum alloy or aluminum;
  - (b) hot rolling said stock;
  - (c) heating the hot rolled stock within about 900° to 960° F;
  - (d) further hot rolling said stock;
  - (e) cold rolling said stock;
  - (f) solution heat treating;
  - (g) cooling;
  - (h) natural aging.
- 52. The method according to claim 51 wherein said alloy contains, by weight, not more than about 0.12% Fe and not more than about 0.1% Si.
- 53. The method according to claim 51 wherein said heating is for more than 2 hours.
- 54. The method according to claim 51 wherein said heating and said solution heat treating is within about 905° to 950° F.
- 55. The method according to claim 51 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.
- 56. A method of producing an aluminum sheet or plate product comprising:
  - (a) providing stock comprising



5,213,639

27

- an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.78% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
- (b) hot rolling said stock;
- (c) heating said hot rolled stock within about 900° to less than 975° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating;
- (f) stretching;
- (g) natural aging.
57. The method according to claim 56 wherein said alloy contains, by weight, not more than about 0.12% Fe and not more than about 0.1% Si.
58. The method according to claim 56 wherein said heating is for more than 2 hours.
59. The method according to claim 56 wherein said heating and said solution heat treating are within about 905° to 950° F.
60. The method according to claim 56 wherein said hot rolling in recitation (b) reduces the thickness by at least 40%.
61. A method of producing a clad aluminum product comprising:
- (a) providing stock comprising:
- (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock, comprising rolling within 600° to 900° F., to a reduction in thickness of at least 40%;
- (c) heating said stock within about 905° to 950° F. for about 3 to 24 hours;
- (d) further hot rolling said stock comprising rolling within 550° to 900° F.;
- (e) solution heat treating at at least 900° F.
62. A method of producing a clad aluminum sheet product comprising:
- (a) providing stock comprising:
- (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock, comprising rolling within 600° to 900° F., to a reduction in thickness of at least 40%;
- (c) heating said stock within about 905° to 950° F. for more than 2 hours;
- (d) further hot rolling said stock comprising rolling within 550° to 900° F.;
- (e) cold rolling said stock to a thickness within 0.03 to about 0.3 inch sheet;
- (f) solution heat treating at a temperature of at least 900° F.
- (g) stretching;
- (h) natural aging.

28

63. A method of producing a clad aluminum product having good strength along with good fracture toughness or good resistance to fatigue crack growth, or both, said method comprising:

- (a) providing aluminous stock comprising:
- (i) an aluminum alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock;
- (c) heating said hot rolled stock within about 900° to 960° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating temperature at at least 900° F.;
- (f) cooling;
- (g) imparting a cold work effect;
- (h) natural aging.
64. A method of producing a clad aluminum product having good strength along with good fracture toughness or good resistance to fatigue crack growth, or both, said method comprising:
- (a) providing aluminous stock comprising:
- (i) an aluminum alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;
- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock;
- (c) heating said hot rolled stock within about 900° to 960° F. for more than 2 hours;
- (d) further hot rolling said stock;
- (e) solution heat treating at at least 900° F.;
- (f) cooling;
- (g) natural aging;
- (h) imparting a cold work effect.
65. In a method wherein an aluminum alloy stock is shaped into an airplane member, the improvement wherein said stock is provided by a method comprising:
- (a) providing aluminous stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;
- (b) hot rolling said stock;
- (c) heating said stock within about 900° to less than 975° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating.
66. In a method wherein an aluminum alloy stock is shaped into an airplane member, the improvement wherein said stock is provided by a method comprising:
- (a) providing aluminous stock comprising:
- (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;

5,213,639

29

- (ii) a cladding thereon of a different aluminum alloy or aluminum;
- (b) hot rolling said stock;
- (c) heating said stock within about 900° to 960° F.;
- (d) further hot rolling said stock;
- (e) solution heat treating.

67. In a method wherein an aluminum alloy sheet is shaped into an airplane member, the improvement wherein said sheet is provided by a method comprising:

- (a) providing aluminous stock comprising:

- (i) an aluminum alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.8% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the remainder substantially aluminum, incidental elements and impurities;

- (ii) a cladding thereon of a different aluminum alloy or aluminum;

- (b) hot rolling said stock, comprising rolling within 600° to 900° F., to a reduction in thickness of at least 40%;

- (c) heating said hot rolled stock within about 900° to 950° F. for more than 2 hours;

- (d) further hot rolling said stock comprising rolling within 550° to 900° F.;

- (e) solution heat treating at at least 900° F.;

- (f) natural aging.

68. In a method wherein an aluminum alloy material is shaped into a vehicular panel, the improvement wherein said material is provided by a method comprising:

- (a) providing aluminous stock comprising an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;

- (b) hot rolling said stock;

- (c) heating said stock within about 900° to less than 970° F.;

- (d) further hot rolling said stock;

- (e) solution heat treating.

69. In a method wherein an aluminum alloy material is shaped into a vehicular panel, the improvement wherein said material is provided by a method comprising:

- (a) providing aluminous stock comprising:

- (i) an aluminum alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the remainder substantially aluminum, incidental elements and impurities;

- (ii) a cladding thereon of a different aluminum alloy or aluminum;

- (b) hot rolling said stock;

- (c) heating said stock within 900° to 960° F.;

- (d) further hot rolling said stock;

- (e) solution heat treating;

- (f) cooling.

70. A product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said product having at least 5% improvement over 2024 alloy in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15ksi $\sqrt{\text{in}}$  or more, or in both said (a) and (b) properties.

30

71. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% iron, not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said product having a long transverse yield strength of 38 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said (a) and (b) properties.

72. An aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 10% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{IC}$  of at least 140 ksi $\sqrt{\text{in}}$ ; (c) a minimum T-L fracture toughness  $K_{app}$  of at least 8 ksi $\sqrt{\text{in}}$ .

73. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 38 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness at least equivalent to a  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  in a test panel around 16 inches wide; (c) a minimum T-L fracture toughness at least equivalent to a  $K_{app}$  of 80 ksi $\sqrt{\text{in}}$  in a test panel around 16 inches wide.

74. An aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.9 manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 39 ksi or more and a minimum T-L fracture toughness  $K_{IC}$  of at least 140 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

75. An aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.78% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 38 ksi or more and a minimum T-L fracture toughness  $K_{app}$  of 80 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

76. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements

5,213,639

31

and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said first alloy on one or more faces thereof, said sheet having a minimum long transverse yield strength of 38 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

77. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said first alloy on one or more faces thereof, said sheet having a minimum long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

78. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said first alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 10% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{IC}$  of at least 140 ksi $\sqrt{\text{in}}$ ; (c) a minimum T-L fracture toughness  $K_{I\text{app}}$  of at least 80 ksi $\sqrt{\text{in}}$ .

79. An aluminum alloy sheet or plate product comprising a first aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more and a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

80. An aluminum alloy sheet product having a core of an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and a minimum T-L fracture toughness  $K_{I\text{app}}$  of 80 ksi $\sqrt{\text{in}}$  or more and a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9.

81. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than

32

about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy having a long transverse yield strength of 39 ksi or more and exhibiting an average fatigue crack growth rate of not over  $1.4 \times 10^{-4}$  inch per cycle for growing a crack from about 1.7 inch to about 1 inch at a frequency of about 25 hertz and a stress ratio  $R$  of 0.1 and a substantially constant  $\Delta K$  of about 30 ksi $\sqrt{\text{in}}$  in an atmosphere of about 90% or more relative humidity.

82. An aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and exhibiting an average fatigue crack growth rate of not over  $1.4 \times 10^{-4}$  inch per cycle for growing a crack from about 1.7 inch to about 1 inch at a frequency of about 25 hertz and a stress ratio  $R$  of 0.1 and a substantially constant  $\Delta K$  of about 30 ksi $\sqrt{\text{in}}$  in an atmosphere of about 90% or more relative humidity.

83. A vehicular panel comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet product having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 10 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

84. Aircraft skin comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet product having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

85. Aircraft skin comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, less than 0.2% iron, less than 0.2% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet product having a minimum long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 15 ksi $\sqrt{\text{in}}$  or more, or in both said properties.

86. Aircraft skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a



33

5,213,639

cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said aluminum product having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{app}$  of at least 80 ksi√in.

87. Aircraft skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 10% above one or more of the levels shown in FIGS. 8 or 9; (b) a T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a T-L fracture toughness  $K_{app}$  of at least 80 ksi√in.

88. Aircraft fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 15 ksi√in or more, or in both said properties.

89. Aircraft fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a T-L fracture toughness  $K_{app}$  of at least 80 ksi√in.

90. Aircraft fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 15 ksi√in or more, or in both said properties.

91. Aircraft fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.9 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.8% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different

34

from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a fatigue crack growth rate not greater than one or more of the levels shown in FIGS. 8 or 9; (b) a T-L fracture toughness  $K_{Ic}$  of at least 150 ksi√in; (c) a T-L fracture toughness  $K_{app}$  of at least 90 ksi√in.

92. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising fuselage skin comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 20 ksi√in or more, or in both said properties.

93. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising an aluminum alloy sheet or plate product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 38 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 150 ksi√in; (c) a minimum T-L fracture toughness  $K_{app}$  of at least 90 ksi√in.

94. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a ΔK level of 20 ksi√in or more, or in both said properties.

95. An aircraft fuselage, or fuselage portion, having reduced tear retarding auxiliary components, said fuselage or portion comprising fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.3 to 0.8% manganese, and containing not more than about 0.15% iron and not more than about 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a minimum long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 150

5,213,639

35

ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 90 ksi√in.

96. An aircraft having a member comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing about 0.01 to 0.15% iron, about 0.01 to 0.15% silicon, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 20 ksi√in or more, or in both said properties.

97. An aircraft having a member comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, less than 0.2% iron, less than 0.2% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 150 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 90 ksi√in.

98. An aircraft having skin material comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, less than 0.2% iron, less than 0.2% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 20 ksi√in or more, or in both said properties.

99. An aircraft having skin material comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.12% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi√in.

100. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness

36

property, or (b) fatigue crack growth rate property at a  $\Delta K$  levels of 20 ksi√in or more, or in both said properties.

101. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, and containing not more than about 0.15% iron and not more than about 0.12% silicon, the balance essentially aluminum and incidental elements and impurities, said aluminum alloy product having a long transverse yield strength of 40 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIGS. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi√in.

102. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy sheet product comprising an aluminum base alloy consisting essentially of, by weight, about 3.8 to 4.5% copper, about 1.2 to 1.8% magnesium, about 0.3 to 0.9% manganese, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more and at least 5% improvement over 2024 in (a) T-L fracture toughness property, or (b) fatigue crack growth rate property at a  $\Delta K$  level of 20 ksi√in or more, or in both said properties.

103. An aircraft having a fuselage skin, said fuselage skin comprising an aluminum alloy product comprising an aluminum base alloy consisting essentially of, by weight, about 4 to 4.5% copper, about 1.2 to 1.5% magnesium, about 0.4 to 0.7% manganese, and containing not more than about 0.15% iron and not more than about 0.12% silicon, the balance essentially aluminum and incidental elements and impurities, and a cladding layer comprising aluminum or an aluminum alloy different from said core alloy on one or more faces thereof, said sheet having a long transverse yield strength of 39 ksi or more together with one or more of the following properties: (a) a maximum fatigue crack growth rate not greater than 5% above one or more of the levels shown in FIG. 8 or 9; (b) a minimum T-L fracture toughness  $K_{Ic}$  of at least 140 ksi√in; (c) a minimum T-L fracture toughness  $K_{Ic}$  of at least 80 ksi√in.

104. A method according to claim 64 wherein said recitation (h) comprises stretching.

105. A method according to claim 63 wherein said recitation (g) comprises stretching.

106. A method according to claim 64 wherein said recitation (h) comprises cold rolling.

107. A method according to claim 63 wherein said recitation (g) comprises cold rolling.

108. A method according to claim 64 wherein solution heat treating is preceded by cold rolling.

109. A method according to claim 63 wherein solution heat treating is preceded by cold rolling.

110. The method according to claim 1 wherein said stock further comprises a cladding on said alloy, said cladding being aluminum or an alloy thereof different than the said alloy.

111. The method according to claim 1 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.

37

5,213,639

38

112. The method according to claim 22 wherein after said solution heat treating, a forming or shaping operation is performed above room temperature.

113. The method according to claim 22 wherein after said solution heat treating, a forming or shaping operation is performed at a temperature of 200° F. or higher.

114. The method according to claim 22 wherein after said solution heat treating, a forming or shaping operation is performed at an artificial aging temperature above room temperature.

115. The method according to claim 22 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.

116. The method according to claim 28 wherein after said solution heat treating, a forming or shaping operation is performed above room temperature.

117. The method according to claim 28 wherein after said solution heat treating, a forming or shaping operation is performed at a temperature of 200° F. or higher.

118. The method according to claim 28 wherein after said solution heat treating, a forming or shaping operation is performed at an artificial aging temperature above room temperature.

119. The method according to claim 28 wherein said hot rolling in recitation (b) reduces the thickness of said stock by at least 40%.

120. The method according to claim 44 wherein after said solution heat treating, a forming or shaping operation is performed above room temperature.

121. The method according to claim 44 wherein after said solution heat treating, a forming or shaping operation is performed at a temperature of 200° F. or higher.

122. In the method according to claim 65 wherein said shaping operation is performed above room temperature.

123. In the method according to claim 65 wherein said shaping operation is performed at a temperature of 200° F. or higher.

124. A product produced by the method of claim 1, 5, 6, 8, 22, 23, 33, 38, 51, 63 or 64.

125. The product according to claim 71 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

126. The product according to claim 76 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

127. The product according to claim 77 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

128. An aircraft skin according to claim 84 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

129. An aircraft according to claim 100 wherein said  $\Delta K$  level is 20 ksi $\sqrt{\text{in}}$  or more.

130. The product according to claim 71 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

131. The product according to claim 76 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

132. The product according to claim 77 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

133. An aircraft skin according to claim 84 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

134. An aircraft fuselage, or fuselage portion, according to claim 94 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

135. An aircraft according to claim 100 wherein said  $\Delta K$  level is 25 ksi $\sqrt{\text{in}}$  or more.

136. The product according to claim 73 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

137. The product according to claim 74 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

138. The product according to claim 75 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

139. The product according to claim 78 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

140. The product according to claim 79 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

141. The product according to claim 80 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

142. An aircraft skin according to claim 86 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

143. An aircraft skin according to claim 87 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

144. An aircraft according to claim 97 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

145. An aircraft according to claim 101 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9.

146. The product according to claim 72 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

147. The product according to claim 73 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

148. The product according to claim 74 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

149. The product according to claim 75 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

150. The product according to claim 78 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

151. An aircraft skin according to claim 87 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

152. An aircraft fuselage skin according to claim 89 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

153. An aircraft fuselage skin according to claim 91 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.



5,213,639

154. An aircraft fuselage, or fuselage portion, according to claim 93 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more.

155 An aircraft according to claim 101 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=20$  ksi $\sqrt{\text{in}}$  or more

156. The product according to claim 72 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

157. The product according to claim 73 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

158. The product according to claim 74 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25$  ksi $\sqrt{\text{in}}$  or more.

159. The product according to claim 75 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

160. The product according to claim 78 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

161. An aircraft skin according to claim 86 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

162. An aircraft skin according to claim 87 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

163. An aircraft fuselage skin according to claim 89 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $AK=25 \text{ ksi}\sqrt{\text{in}}$  or more.

164. An aircraft fuselage skin according to claim 91 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

165. An aircraft fuselage, or fuselage portion, according to claim 93 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25$  ksi $\sqrt{\text{in}}$  or more.

166. An aircraft according to claim 101 wherein said maximum fatigue crack growth rate is not greater than one or more of the growth rate levels shown in FIG. 8 or 9 at  $\Delta K=25 \text{ ksi}\sqrt{\text{in}}$  or more.

167. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

168. The product according to claim 78 wherein said product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

169. An aircraft skin according to claim 86 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

170. An aircraft skin according to claim 87 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 140 ksi $\sqrt{\text{in}}$  or more.

189. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 150 ksi√in or more.

60 190. An aircraft according to claim 101 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 150 ksi $\sqrt{\text{in}}$  or more.

191. An aircraft according to claim 103 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{IC}$  of 150 ksi $\sqrt{\text{in}}$  or more.

192. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi $\sqrt{\text{in}}$  or more.

5,213,639

41

193. An aircraft skin according to claim 86 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi√in or more.

194. An aircraft skin according to claim 87 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi√in or more.

195. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 80 ksi√in or more.

196. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

197. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

198. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

199. The product according to claim 78 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

200. The product according to claim 80 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

201. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

202. An aircraft according to claim 101 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

203. An aircraft according to claim 103 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 85 ksi√in or more.

204. The product according to claim 73 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

205. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

206. The product according to claim 75 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

207. The product according to claim 78 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

208. The product according to claim 80 wherein said product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

209. An aircraft skin according to claim 86 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

210. An aircraft skin according to claim 87 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

211. An aircraft fuselage skin according to claim 89 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

212. An aircraft according to claim 101 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

42

213. An aircraft according to claim 103 wherein said aluminum alloy product has a minimum T-L fracture toughness  $K_{Ic}$  of 90 ksi√in or more.

214. The product according to claim 73 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

215. The product according to claim 79 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

216. The product according to claim 80 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

217. An aircraft skin according to claim 84 wherein said fatigue crack growth rate level is at  $\Delta K = 20$  ksi√in or more.

218. An aircraft skin according to claim 86 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

219. An aircraft skin according to claim 87 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

220. An aircraft fuselage skin according to claim 89 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

221. An aircraft fuselage skin according to claim 91 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

222. An aircraft according to claim 101 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 20$  ksi√in or more.

223. The product according to claim 78 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

224. The product according to claim 79 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

225. The product according to claim 80 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

226. An aircraft skin according to claim 86 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

227. An aircraft skin according to claim 87 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

228. An aircraft skin according to claim 89 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

229. An aircraft fuselage skin according to claim 91 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

230. An aircraft according to claim 101 wherein said fatigue crack growth rate levels for FIG. 8 or 9 are at  $\Delta K = 25$  ksi√in or more.

231. The product according to claim 81 wherein said average fatigue crack growth rate is not over  $1.25 \times 10^{-4}$  inch per cycle.

232. The product according to claim 82 wherein said average fatigue crack growth rate is not over  $1.25 \times 10^{-4}$  inch per cycle.

UNITED STATES PATENT AND TRADEMARK OFFICE  
CERTIFICATE OF CORRECTION

PATENT NO. : 5,213,639

DATED : May 25, 1993

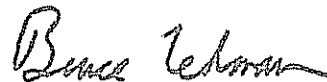
INVENTOR(S) : Edward L. Colvin et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 14, line 14	Before "21.4 x 10 <sup>-5</sup> " insert --at--
Col. 30, line 23, Claim 72	Change "8 ksi $\sqrt{\text{in}}$ " to --80 $\sqrt{\text{ksi in}}$ --
Col. 31, line 22, Claim 77	Before "ksi $\sqrt{\text{in}}$ " insert --15--

Signed and Sealed this  
Fifth Day of July, 1994

Attest:



BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks